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Minnie & Nellie Bowen.
4th. Class.
Cambridge High School

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SO_2	Sulphurous acid.	32
KO	Potassa.	47
NaO	~~Natron~~ Soda.	31
CaO	Calcia.	28

14
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40 : 14 :: 12 : 4.2

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28 [illegible]

SCIENCE

FOR THE

SCHOOL AND FAMILY.

PART I.

NATURAL PHILOSOPHY.

BY

WORTHINGTON HOOKER, M.D.,

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By Dr. Worthington Hooker.

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PREFACE.

Daniel Webster, in his Autobiography, speaks thus of his entering upon the study of law: "I was put to study in the old way—that is, the hardest books first, and lost much time. I read Coke on Littleton through without understanding a quarter part of it. Happening to take up Espinasse's Law of Nisi Prius, I found I could understand it; and arguing that the object of reading was to understand what was written, I laid down the venerable Coke *et alios similes reverendos*, and kept company for a time with Mr. Espinasse and others, the most plain, easy, and intelligible writers. A boy of twenty, with no previous knowledge on such subjects, can not understand Coke. It is folly to set him on such an author. There are propositions in Coke so abstract, and distinctions so nice, and doctrines embracing so many conditions and qualifications, that it requires an effort not only of a mature mind, but of a mind both strong and mature, to understand him. Why disgust and discourage a boy by telling him that he must break into his profession through such a wall as this? I really often despaired. I thought that I never could make myself a lawyer, and was almost going back to the business of schoolkeeping. Mr. Espinasse, however, helped me out of this in the way that I have mentioned, and I have always felt greatly obliged to him."

Here is most graphically depicted a defect which is now, as it was then, very prominent in all departments of education. It is even

more so in early education than in that of the college and the professional school. Even in tender childhood pupils are put to studying books of which, as was true of Webster with his Coke on Littleton, they do not understand "a quarter part." If the rule is not "the hardest books first," there are many things in the books that it is not only hard but impossible for them to understand. And the hardest things are often put first. For example, in a very popular primary geography which lies before me the pupil is introduced to the world and its grand divisions at the outset, while he is taught about his own state and country only at the conclusion of the book. And this unnatural mode is the one very commonly pursued. Similar criticism can be passed upon most of the books used in teaching young children. Some of them are wholly useless. This is true of the grammars for primary schools. The formal statements, called the rules of grammar, are beyond the understanding of very young scholars, and therefore are useless burdens upon their memories. They are as useless to them as the three-fourths of Coke which Webster could not understand was to him.

If we follow education upward from the primary school we find the same defect throughout the whole course. In the books which are used in teaching natural science it is especially prominent. Even in the elementary books, or compendiums, so called, formal propositions and technical terms render the study uninviting, and to a great extent unintelligible. The pupil is apt to be disgusted and discouraged, as Webster was with Coke on Littleton, and for the same reason.

Another defect intimately connected with that of which I have spoken is the very sparing and late introduction of the physical sciences. They are generally postponed to the latter part of the course of education, and then but little time is devoted to them. Generally, when a pupil designs to go through college, the study of these sci-

ences is wholly neglected in his preparation, because a knowledge of them is not required for admission. Then in the college they are not attended to till the latter part of the course, and in the short time allotted to them there is so much to be learned that the teaching of them is a failure. Especially is this true of Chemistry and Geology.

This defect is a *radical* one. A thorough change should be effected in this respect in the whole course of education. The natural sciences should be made prominent from the beginning to the end, not only because they are of practical value, but also because they are as useful in their way for mental discipline as the study of mathematics and of language. They can be taught to some little extent to the youngest pupils. There are facts about air, water, and the various objects that they see around them, which they can understand if they be presented in the right manner. And the busy inquiries which they make after the reasons of the facts, and their appreciation of them if stated simply and without technical terms, show the appropriateness of such teaching. Children are really very good philosophers in their way. They have great activity not only of their perceptive but of their reasoning faculties also, to which due range should be given in their education.

Beginning thus, not a year should pass during the whole course when the pupil shall not be engaged in studying some one of the physical sciences to some extent. This continued attention to such studies in a reasonable amount, so far from interfering with the due prosecution of the other studies deemed so essential, *will so promote the pupil's advance in them as to more than make up for the time that is taken from them.* It will do this not only by the genial influence which such studies exert upon the mind, but by the contributions which they make to the knowledge of language and mathematics; for language is largely built up from natural objects and from the ac-

quisitions of science, and there is an abundance of interesting applications of portions of the mathematics in the facts which the physical sciences develop to us.

I have said that the teaching of the natural sciences in our colleges is generally a failure, and it always will be so as long as the present plan is continued. In order to have it successful there must be *the same gradation in teaching them that we have in teaching language and the mathematics.* The college student needs to be prepared for the lectures which he hears on natural philosophy, chemistry, etc., and for his study of those branches, by previous familiarity with the simpler portions of them acquired in the school-room.

There is another very important reason for the early introduction of the physical sciences into education. By far the larger portion of pupils in our schools stop short of the college, or even the academy and high school. That they should go forth into the world with no knowledge of the principles that lie at the basis of the arts in which so many of them are to engage is a shame and a wrong, if the communication of such knowledge be indeed practicable, as it undoubtedly is. Even those who are not to engage in these arts will be greatly benefited by this knowledge, because in addition to its constant practical applications in the management of life, it will contribute to their mental power, and, what is no small consideration, to their enjoyment; and it is in fact requisite to constitute them well-informed persons.

If the views which I have presented be correct, there should be a series of books on the natural sciences carefully adapted to the different periods of the course of study. Those intended for the young beginner should be exceedingly simple, and should not attempt to present any thing like a full view of the subjects treated. They should deal largely with familiar facts or phenomena. The termin-

ology of science and formal statements of principles, such as we often see in so-called compendiums, should have no place in them, but should be gradually introduced as the series advances, and should be made complete only in the concluding books.

It has been the object of the author to supply a part of such a series. The first book in the series is the "Child's Book of Common Things," intended to teach the observation of familiar facts, or, in other words, the beginnings of philosophy, to children as soon as they have got well started in reading. Next comes the "Child's Book of Nature," which in its three parts (Part I., Plants; Part II., Animals; Part III., Air, Water, Light, Heat, etc.) extends considerably the knowledge of the philosophy of things which the child has obtained from the first book in the series. Then follows the "First Book in Chemistry." On a level with this is my "First Book in Physiology." The next step in the gradation brings us to three books under one title, "Science for the School and the Family;" Part I., Natural Philosophy; Part II., Chemistry; Part III., Mineralogy and Geology. On a level with these is another book, "Natural History," and another still is to be written, an "Introduction to Botany."

The three books, of which the present is one, are intended for the older scholars in what are commonly called grammar-schools. At the same time they are suited to scholars who are advanced to a higher grade who have not gone through the previous books of the series. The preparation of books especially adapted to high schools and colleges I have left to others, except in one branch of science, Physiology, on which I some years ago published a work entitled "Human Physiology."

All of these books are from the press of Harper and Brothers except the two works on Physiology, published by Sheldon and Co.,

New York, and the "Child's Book of Common Things," published by Peck, White, and Peck, New Haven.

The general plan and style of these books are very different from what we see in most of the books for schools on the same subjects. The order of the subjects and the mode of developing them differ from the stereotype plan which has so generally been adopted. One prominent feature is the free use of illustrations from *familiar* phenomena. This leads the pupil to reason or philosophize about common things, thus giving an eminently practical character to his knowledge. At the same time it makes the books suitable for use in the family as well as the school, between which there should be more common ground than the present mode of education allows.

The style which I have chosen for all the books I have written for use in teaching is what may be called the *lecture style*. There are three other kinds of style which are more commonly used in school-books. The most common is what I term the *formal statement style*. In this principles and rules are stated, and then illustrations are given. This makes a formal and uninviting book. The bare skeleton of the science is generally for the most part presented, and the young pupil is apt to learn the statements by rote without understanding them. It is a style fitted only for books intended for advanced scholars. Another style is the *catechetical*. This is an unnatural mode of communicating knowledge; and besides, it encourages learning by rote as the formal statement style does. In the third style, the *dramatic*, conversations are held between the teacher and some learners. The chief objection to this is that it undertakes to put in permanent shape what should be extemporized in the recitation. What is needed in the book is simply clear and concise statement in an interesting style, and the living teacher and his

scholars can best furnish the conversational element as the recitation goes on.

In the lecture style there may be and should be as much precision of statement as in the formal statement style, while it is more interesting, because it is the natural mode of communicating knowledge. In this style the facts are ordinarily so stated as to develop principles; while in the other the order is reversed, the principles being first stated and the facts given afterward. One of the most successful books ever used in our colleges—"Paley's Natural Theology"—is in the lecture style, and it is a matter of surprise that this fact has had so little influence with those who have prepared books for instruction.

Whatever may be true of advanced scholars, in teaching the *young* student in science bare, dry statement should be avoided, and the subjects should be presented in all their attractive features. I would not be understood as advocating the dressing up of science in adventitious charms. This is not necessary. Science possesses in itself an abundance of charms, which need only to be properly developed to attract the young mind; and the lecture style furnishes the best vehicle for such a development.

One grand essential for giving interest to any study is the presentation of the various points in the *natural order* in which they should enter the mind. *They should be so presented that each portion of a book shall make the following portions more interesting and more easily understood.* This principle, which is so commonly transgressed, I have endeavored to observe strictly in the preparation of these volumes.

Questions are put at the end of this book for those teachers who desire to use them. There is also an Index.

W. HOOKER.

January, 1863.

CONTENTS.

NATURAL PHILOSOPHY.

CHAPTER I.

MATTER.

1. **Matter and Spirit.**—The distinction between matter and spirit is almost universally recognized even by those who have given little thought to such subjects. It is a distinction of which we are conscious in our own persons. We know instinctively that there is a something within us that causes the movements of our material bodies, and that something we call spirit.

2. **Bishop Berkeley's Ideas.**—Some philosophers, in their speculations, have denied that there is any such thing in existence as matter. Bishop Berkeley, for example, taught that the impressions which we suppose that we receive from material objects do not come from real substances, but are the "effects of the immediate agency of an ever-present Deity." It is no wonder that the wisdom and learning of a man who could seriously adopt such a belief could not save him from being the dupe of quackery. He believed that tar-water was a sovereign cure for all diseases; and Dr. Holmes playfully remarks of him, that "he held two very odd opinions: that tar-water was every thing, and that the whole material universe was nothing."

3. **Hume's Ideas.**—The infidel Hume went beyond Bishop Berkeley, denying even the existence of the soul as an individual and responsible agent. He made every thing to consist of ideas and impressions, and said that these have no necessary connection, but are "a bundle of perceptions that succeed each other with inconceivable

rapidity, and that therefore I myself of to-day am no more the I myself of yesterday or to-morrow than I am Nebuchadnezzar or Cleopatra." A wag proposed the following epitaph for his tomb-stone as a suitable illustration of his theory:

> "Under this circular idea, vulgarly called tomb,
> Impressions and ideas rest which constituted Hume."

4. **Origin of the word Spirit.**—The name spirit came originally from an attenuated form of matter, the air or breath, because the air, like spiritual existence, is invisible. The formation of language is to a large extent thus based on analogies.

5. **Spirit not an Object of Sense.**—None of the senses can perceive spirit itself, though they perceive the effects which spirit produces on material substances. If, for example, you move your arm, it is the spirit within you, acting upon the muscles through the nerves, that causes it to move; and you see here the effects produced by spirit upon matter, but you do not see the spirit itself.

6. **Effects of Matter on the Senses.**—Some forms of matter can be perceived by all the senses; others can be perceived by only a part of them; some by only one. Air you can not see, nor smell, nor taste; but you can feel it, and hear the sound of its motion. Sometimes matter affects only the sense of smell, or that with the sense of taste. Sea-air smells salt; but the salt in the air is so finely divided that we can not see it. And yet it is the salt, entering the nostrils and coming in contact with the extreme fibres of the nerve of smell, that produces the effect. So when we smell a flower, matter comes from it in particles so fine that no microscope can detect them, but they produce sensation when they strike upon the nerve.

7. **Forms of Matter.**—Matter appears in three forms: solid, liquid, and gaseous or aeriform—that is, like air. Sometimes matter is spoken of as having only two forms —solid and fluid. In this case fluids are divided into

two classes, the elastic and non-elastic. The air and the various gases and vapors are the elastic fluids; while those which are called liquids are the non-elastic fluids. A foot-ball bounds because the air in it is an elastic fluid. If it were filled with a non-elastic fluid, as water, it would not bound. When water takes the form of steam it is an elastic fluid. Though it is very common to use the expression elastic fluids, the division of matter into three forms is the one usually recognized.

8. **Solids.**—In solid matter the particles can not be moved about among each other; but each particle generally retains the same position in relation to those particles which are around it—in other words, it does not change its neighborhood. This is more true of some solids than of others. It is absolutely true of such hard solids as granite and the diamond. In these the particles are always in the same relative position. But it is not so with gold or lead. By hammering these you can change greatly the relative position of their particles. India-rubber is a solid, but the relative position of its particles can be much altered in various ways.

9. **Liquids.**—It is the grand characteristic of a liquid that its particles change their relative position from the slightest causes. It is in strong contrast with solids in this respect. When you move any portion of a solid body you move all the other portions of it, and generally in the same direction. But a body of liquid can not be moved all together as one body except by confining it; as, for example, in the case of a water-pipe or a syringe. And then, the moment that the water can escape, the particles use their liberty of altering their relative position. As wind and other agents act continually upon water, no particle stays for any length of time in the neighborhood of the same particles. "Unstable as water" is, then, an exceedingly significant expression. Water is never at rest. A particle of it may at one time be floating on the surface of the ocean, and at another be

in depths beyond the sounding of man. It flies on the wings of the wind, falls in the rain, runs in the stream, is exhaled from a leaf, trembles in the dew-drop, flows in the blood of an animal or in the sap of a plant, and is always ready to be jostled along in its ever-changing course.

10. **Gases.**—The particles of gaseous or aeriform substances move among each other even more freely than those of a liquid. Air, therefore, is more unstable and restless than water. Even when the air seems to be perfectly still its particles are moving about among each other. You can see this to be true if you darken a room, leaving a single shutter a little open. Where the light enters you will see motes flying about in every direction, which would not be the case if the air were really at rest. The particles of air have a greater range of travel than those of water; for the sea of atmosphere which envelops the earth rises to the height of about fifty miles. How far water rises in its evaporation we know not; but it is not at all probable that it rises to the uppermost regions of the atmosphere.

11. **Filling of Spaces by Liquids and Gases.**—It is the freeness with which the particles of liquids and gases move among each other that enables them to insinuate themselves into spaces every where. They are ever ready to enter into any substances which have interstices or pores of such size as will admit them. There are mingled with the grains of the soil not only water, but air and gases. These are present also in all living substances, both vegetable and animal. Water is the chief part of sap and of blood, and air and gases always go with water. Part of the air that we breathe in enters the blood in the lungs, and courses with it through the system. The fishes could not live in water if there were not air mingled with it. This can be proved by experiment. If you put a fish into a close vessel it will soon die, because it uses up all the air that is in the water.

In an open vessel the fish is kept alive by the constant accessions of fresh air to the water.

12. **Solution.**—In solutions of solid substances in water it is the freedom with which the particles of water move about among each other that enables them to take in among them the minute particles of the solid. And when water ascends into air by evaporation it may be said to be a real solution of water in the air; for the particles of water mingle with those of the air, just as the particles of a solid mingle with those of water in a solution.

13. **Relation of Heat to the Forms of Matter.**—Some kinds of matter are seen in all the three forms. Whether these shall assume one form or another depends on the amount of heat present. Thus when water is solid, ice, it is because a part of its heat is gone. Apply heat, and it becomes a liquid, water. Increase the heat to the boiling point, and it becomes steam, or an aeriform substance. Alcohol has only two forms—liquid and aeriform. It has never been known to be frozen. Iron is usually solid; but in the foundry, by the application of great heat, it is made liquid. Mercury is liquid in all ordinary temperatures; but it often becomes solid in the extreme cold of arctic winters. A mercurial thermometer is of course useless under such circumstances, and the alcoholic thermometer is relied upon to denote the degree of cold. The difference between mercury, water, and iron in regard to the liquid state is this: It takes but little heat, comparatively, to make mercury liquid, while more is required for this condition in water, and much more for it in the case of iron.

14. **The Nature of Matter Unknown.**—What now, let us inquire, do we know of the nature of matter? Can we say that we know any thing of it? We may observe its phenomena, and learn its properties; but with our most searching analyses of it we can no more determine what matter is than we can what spirit is. Newton sup-

posed "that God in the beginning formed matter in solid, massy, hard, impenetrable particles." This he believed to be true of liquids, and even of gases, as well as solids. In the gas these hard particles are much farther apart than in the solid. The supposition is a very probable one; but if it be true it does not let us know what matter is, for it leaves us in the dark as to the nature of the particles. Newton farther supposed that these particles have always remained unaltered amidst all the changes that are taking place; these changes being occasioned by "the various separations and new associations and motions of these permanent particles." When, for example, any thing is burned up, as it is expressed, not one of these particles is either destroyed or altered, but they merely take on new arrangements. Though most of the substance has flown off in the form of gas, the ultimate particles composing the gas are the same now that they were when making a part of the solid substance; and they may soon again become a part of some new solids. Such changes in the forms of matter are every where going on; and when you become acquainted with Chemistry, in the Second Part, you will be familiar with them.

15. **Atomic Theory.**—These ultimate particles of matter are so minute that they have never been seen by man. The smallest particle that can be seen with the most powerful microscope is probably made up of very many of them united together. These ultimate particles we term atoms; and the theory in regard to the composition by them of different substances is called the atomic theory. The atoms of different substances are not supposed to be alike, but to differ in both size and weight. This theory will be more particularly noticed in the Second Part.

16. **Imponderable Agents.**—There are certain agents—light, heat, electricity, etc.—which are supposed by some to be forms of matter. If they are, they are exceedingly

attenuated; for their presence, as has been proved by many experiments, never adds in the least to the weight of any substance. They have therefore been styled imponderable agents. Their agency is of great importance and very active, producing every where constant changes. Two of them—heat and light—are obviously and immediately essential to life. What their real nature is remains as yet an entire mystery.

CHAPTER II.

PROPERTIES OF MATTER.

17. **Variety in the Properties of Matter.**—All matter has properties or qualities. Some of these are different in the different kinds of matter. Thus its three forms have different properties, as you saw in Chapter I. There is variety also in the properties of substances of the same class. Thus liquids are unlike each other in some respects. Some, for example, are lighter than others. Oil is lighter than water. Gaseous substances also differ in this and in other respects. But the variety in the properties of solids is greater than in those of gases or liquids. This will appear as I proceed.

18. **Divisibility of Matter.**—Any visible portion of matter can be divided into parts. Even if it be so small that you can see it only with a powerful microscope, it could still be divided if you could have an instrument sufficiently fine for the purpose. *Divisibility*, then, is said to be a *general* property of matter; that is, a property belonging to all kinds of matter.

19. **Examples of Minute Division of Matter.**—There are numerous examples in which the division of matter is carried far beyond that which can be effected by any cutting instrument. Some of these I will notice:

A gold-beater can hammer a grain of gold into a leaf

covering a space of fifty square inches. So thin is it that it would take 282,000 of such leaves, laid upon each other, to make the thickness of an inch. And yet so even and perfect is this thin layer of gold, that when it is laid upon any surface in gilding it has the appearance of solid gold. A fifty millionth part of this grain of gold thus hammered out can be seen by the aid of a microscope which magnifies the diameter of an object ten times. But the division of gold is made even more minute than this in the manufacture of the wire of gold-lace. It is done in this way: A bar of silver weighing 180 ounces is covered with a layer of gold weighing an ounce. It is then drawn through a series of holes in a steel plate, diminishing in diameter, till it at length comes out a very fine wire 4000 feet long. Each foot of it then has only the one 4000th part of the ounce of gold, and yet the silver is well covered.

A soap-bubble is a beautiful example of the minute division of matter. That thin wall which incloses the air which you have blown into it is composed of particles of the soap and of the water mingled together. It is supposed to be less than one millionth of an inch in thickness.

The thread of the silk-worm is so minute that the finest sewing-silk is formed of many of these threads twisted together. But the spider spins much more finely than this. The thread by which you see him letting himself down from any height is made up of about 6000 threads or filaments, each coming from a separate hole in his spinning machine. A quarter of an ounce of the thread of a spider's web would extend 400 miles.

A grain of blue vitriol, dissolved in a gallon of water, will make the whole blue. Such a diffusion could not be without an exceedingly minute division of the particles.

Perhaps the most minute division of matter is exemplified in odors. A grain of musk will scent a room for years, and yet have no perceptible loss of weight. But

all this time the air is filled with fine particles coming from the musk.

The microscope reveals to us many wonderful examples of the minuteness of the particles of matter, both in the vegetable and the animal world.

If you press a common puff-ball a dust flies off like smoke. Examined with a microscope, each particle of this dust, which is the seed of the plant, is a perfectly round orange-colored ball. This ball is of course made up of very many particles, arranged in this regular form. Beautiful examples of various arrangements of the minute particles of matter we have in the pollen of different plants, as seen with the microscope.

Each particle of the dust which adheres to your fingers as you catch a moth is a scale with fine lines upon it regularly arranged. And if you look through the microscope at the wing of the moth, you will see, where the dust is rubbed off, the attachments by which the scales were held standing up from the surface of the wing, like nail-heads on a roof where the shingles have been torn off.

The organization of exceedingly small animals, as revealed by the microscope, furnishes us with wonderful examples of the minute division of matter. A little of the dust of guano, examined through a powerful microscope, is seen to contain multitudes of shells of various shapes. These shells are the remains of animalcules that lived in the water, their destiny seeming to be in part to furnish food to other animals larger than themselves. In the chalk formations of the earth are seen multitudes of such shells. They have been discovered even in the glazing of a visiting-card; for they are so small that the fine grinding up of the chalk does not wholly destroy them. There are animals, both in the air and in the water, so small that it would take millions of them to equal in bulk a grain of sand, and a thousand of them could swim side by side through the eye of a common-sized needle. Now in all these animals there are organs, con-

structed of particles of matter, which are arranged in them with as much order and symmetry as in the organs of our bodies. How minute then must these particles be!

How do such facts extend our views of the power of the Deity! The same power that moulded the earth, sun, moon, and the whole "host of heaven," gave form, and life, and motion to the millions which sport in every sunbeam; the same eye that watches the immense heavenly bodies as they move on in their course, looks upon one and all of these legions of animals in earth, air, and water, though they are unseen by human eyes, seeing that every particle shall take its right position, so that this part of creation may with all the rest be pronounced very good; and the same bountiful hand that dispenses the means of life and enjoyment to the millions of the human race, forgets not to minister to the brief life and enjoyment of each one of these myriads of animalcules, though they seem to be almost nothingness itself.

20. **Pores and Spaces in Matter.**—In all matter there are spaces about the particles. Those bodies which are called porous have quite large spaces in them. But even in those which are not commonly considered porous the particles are by no means close together. A celebrated experiment tried in Florence a long time ago showed that there are spaces among the particles of so dense a substance as gold sufficiently large to let water through them. A hollow golden globe containing water was subjected to great pressure, and its surface was bedewed with the water that came out through the pores of the gold. In all substances in which there are pores visible to the naked eye, or by the aid of the microscope, there are other spaces or interstices among the particles around the pores. Indeed, it is supposed that there is space around every ultimate particle or atom, and that no two of these atoms are in actual contact. The fact that substances which have no pores can be compressed into a smaller space than they usually occupy shows that there

are spaces or interstices in them. Solids can be thus compressed, some more than others. But the most compressible substances are the gases and vapors. The amount of space between their particles must be very large to allow of so great compression.

21. **Space in Gaseous Substances.**—We can have some idea of the great amount of space in a gaseous or aeriform substance by observing the difference between water in its liquid and in its aeriform state. A cubic inch of water, when it becomes steam, occupies 1696 times as much room as it did when it was water. The difference in proportion is exhibited in Fig. 1, the inner circle representing the water, and the outer the steam into which it is converted. Now the water is not altered at all in its nature by being changed into steam. The particles are simply put farther apart by the heat, and as soon as the heat is withdrawn they come together again to form water, or, in other words, the steam is condensed into water. It is plain, therefore, that the space between the particles is 1696 times as great in steam as it is in the water from which the steam is made.

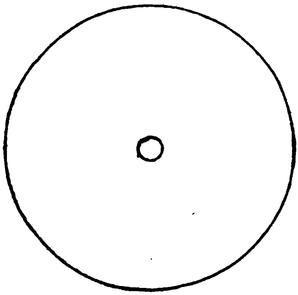

Fig. 1.

22. **Solutions.**—When any substance, as sugar or salt, is dissolved in water, its particles are diffused through the spaces that exist between the particles of the water. So also when water evaporates (§ 12), the particles of water are diffused through the spaces between the particles of the air. In like manner are the particles from an odorous substance diffused in these spaces, and thus mingled with the particles of the air they are carried into the nostrils, and strike upon the minute extremities of the nerve of smell.

23. **Relation of Heat to the Spaces of Matter.**—The variation in the amount of space between the particles of matter in any substance generally depends on the variation of the amount of heat present. Thus heat expands iron; that is, it increases the spaces between the particles of the iron. So also heat increases the spaces between the particles of mercury, and thus makes it occupy more room in the thermometer. This effect of heat will be considered more fully hereafter.

The general views which I have given of the constitution of matter will throw light upon the different qualities of different substances, some of which I will notice.

24. **Density and Rarity.**—The density of a substance depends upon the quantity of matter it contains in a given space. The more dense, therefore, a substance is the greater is its weight. A piece of lead is forty times heavier than a piece of cork of the same size. Mercury is nearly fourteen times heavier than an equal bulk of water. You see, then, that density must depend on the nearness of the atoms to each other. In so dense a substance as gold the atoms are all very close together; in wood there are spaces, some of which are so large that you can see them; and in air, steam, and the gases there is a great deal of space among the particles (§ 21), so that we speak of their *rarity* instead of their density.

25. **Tenacity.**—The power of holding together, termed tenacity, depends on the degree of attraction between the particles. By attraction I mean a disposition in particles to come together, this disposition being manifested in opposition to any force tending to draw them apart. I shall soon speak of this more particularly. Tenacity does not exist at all in gaseous substances. The particles of air and of steam, for example, show no disposition to cling together; that is, have no tenacity. This property is weak in liquids. It is only strong enough in water to enable its particles to hang together in the shape of a drop. It is strong in solids, enabling their particles not

only to hold together in large quantities, but to hold up also heavy weights suspended to them. It is stronger in iron than in any other solid. It is stronger in wrought iron than in cast iron; and strongest of all in steel.

26. **Comparative Tenacity of Substances.**—Various metals and other substances have been tested in reference to their comparative tenacity. It was done in this way: Wires were made of the metals, all of the same size. Weights were suspended to them, and additions were made to the weights by little and little till the wires broke. The table underneath was made by placing against each metal the greatest weight that its wire would hold:

Cast steel	134 pounds.
Best wrought iron	70 pounds.
Cast iron	19 pounds.
Copper	19 pounds.
Silver	11 pounds.
Gold	9 pounds.
Tin	5 pounds.
Lead	2 pounds.

Oak wood, tried in the same way, was found to hold up 12 pounds, one more pound than silver. Some animal substances have great tenacity, as the thread of the silkworm, hair, wool, and the ligaments and tendons of our bodies and of other animals.

27. **Value of Tenacious Substances.**—"The gradual discovery," says Dr. Arnot, "of substances possessed of strong tenacity, and which man could yet easily mould and apply to his purposes, has been of great importance to his progress in the arts of life. The place of the hempen cordage of European navies is still held in China by twisted canes and strips of bamboo; and even the hempen cable of Europe, so great an improvement on former usage, is now rapidly giving way to the more complete and commodious security of the iron chain—of which the material to our remote ancestors existed only as useless stone or earth. And what a magnificent

spectacle is it, at the present day, to behold chains of tenacious iron stretched high across a channel of the ocean, as at the Menai Strait between Anglesea and England, and supporting an admirable bridge-road of safety, along which crowded processions may pour, regardless of the deep below, or of the storm; while ships there, with sails full-spread, pursue their course unmolesting and unmolested."

28. **Hardness.**—This property seems to depend upon some peculiar arrangement of the particles of matter. We should suppose that the densest substances would be the hardest. But it is not so. Iron is the hardest of the metals, but its particles are not so close together as those of gold, which is quite a soft metal. And gold is five times as heavy as the diamond, which is so hard as to cut glass easily. Common flint is hard enough to scratch glass, but will not cut it like the diamond.

29. **Flexibility and Brittleness.**—If you bend a flexible body as a piece of wood, as represented in Fig. 2, it is obvious that the particles on the upper or convex side must be put a little farther apart, while those on the under or concave side are brought a little nearer together. But the wood does not break, because the particles that are thus moved a little apart still retain their hold upon each other. This is the explanation of what we call flexibility. On the other hand, the particles in a rod of glass can not be put farther apart in this way. They are not actually in contact any more than the particles of the wood are (§ 20), but they are in a *fixed* relative position; that is, a position which can not be disturbed without a *permanent* separation of particles. If you attempt to bend the rod there is no slight separation of many particles, as in the bent wood, but a full and permanent separation in some one part of the rod. We call the property on which this

Fig. 2.

result depends brittleness. Brittle substances are generally hard. Glass, while the most brittle of all substances, is hard enough to scratch iron. Brittle substances also have much tenacity. A rod of glass can hold up a heavy weight, although a slight blow suddenly given would break it.

30. **Flexible and Brittle Steel.**—There are two kinds of steel, flexible and brittle. The steel of most cutting instruments is brittle. The steel of a sword-blade is quite flexible, and that of a watch-spring is so much so that we can wind it up in a coil. This difference is owing to a difference in the mode of cooling the steel. If it be cooled suddenly, it is brittle; if slowly, it is flexible. The process by which it is cooled slowly is called *annealing*. The explanation of all this is quite plain. The steel being expanded by heat—that is, its particles being put farther apart than they usually are—when they are suddenly brought together again they have not time to arrange their relative position properly. Brittleness is therefore the result. But, on the other hand, when the cooling is effected gradually, time is given for the arrangement.

31. **Tempering of Steel.**—Steel suddenly hardened is too brittle for common use. A process called tempering is therefore resorted to for diminishing the brittleness. The steel is reheated after the hardening, and is then allowed to cool slowly. The degree in which the brittleness is lessened depends on the degree of heat to which the steel is subjected. It can be entirely removed by a red heat, for then the particles have a full opportunity to readjust themselves; and the more the heat comes short of this point the less thorough will be the adjustment, because the less perfectly are the particles released from their suddenly-taken position. In lessening the brittleness we lessen hardness also, and therefore the tempering is varied in different cases according to the degree of hardness which is desired.

32. **Annealing of Glass.**—Glass is always annealed. If this were not done our glass vessels and windows would be exceedingly brittle, and would therefore be constantly breaking. Articles made of glass are annealed by being passed very slowly indeed through a long oven which is very hot at one end, the heat gradually lessening toward the other end.

33. **Prince Rupert's Drops.**—We have a striking example of brittleness induced by sudden cooling in what are called Prince Rupert's drops. These are made by dropping melted green glass into cold water, and they are of the shape represented in Fig. 3. If you break off ever so small a bit of the point of one of these drops, the whole will at once shiver to pieces. That is, the sudden arrangement of the particles is so slight and unnatural that the disturbance of the arrangement in a small part suffices to destroy the arrangement of the whole, very much as a row of bricks falls over from the fall of the first in the row. Mr. Farraday says that these drops were not, as is commonly supposed, invented by Prince Rupert, but were first brought to England by him in 1660. They excited much curiosity at that time, and were considered "a kind of miracle in nature." But you see that this, like many other wonders, receives with a little thought an easy explanation.

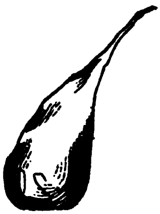

Fig. 3.

34. **Malleability and Ductility.**—Those metals which can be hammered into thin plates are called malleable. Gold furnishes us with the best illustration of this property. Silver, copper, and tin are quite malleable. Most of the other metals are very little so, and some of them are not at all, breaking at the first blow. A substance is said to be *ductile* when it can be drawn out into wire. The principal metals that have this quality are platinum, silver, iron, copper, and gold, and in the order in which

I have named them. Melted glass is very ductile. It can be drawn out in a very fine thread, and when this thread is cut and arranged in branches it resembles beautiful white hair. In hammering metals into plates, or drawing them into wire, there is a considerable change of relative position in the particles, similar to that which we have in fluids, though nothing like as free. In this change of position those particles that do remain in close neighborhood have a remarkable tenacity or attraction, preventing their separation. In welding two pieces of iron, which is done by the blacksmith by hammering them together when red-hot, there must be enough movement among the particles to have those of one piece mingle somewhat with those of the other.

35. **Compressibility.**—Porous substances can be considerably compressed. Force applied to them can bring their particles nearer together, making them to fill up in part their pores. The most familiar example you have of this is in sponge. The more porous wood is the more can it be compressed. But even such dense substances as the metals can be compressed in some degree; that is, the interstices between their particles can be made smaller. Medals and coins have their figures and letters stamped upon them by pressure, just as impressions are made upon melted sealing-wax. The heavy and quick pressure required to do this actually compresses the whole piece of the hard metal, putting all the particles nearer together, so that it occupies less space than it did before it was stamped.

36. **Incompressibility of Liquids.**—We should suppose, from the freeness with which the particles of liquids move among each other, and from the spaces (§ 22) which exist among them, that these substances could be easily compressed. But it is not so. The heaviest pressure is required to compress them even in a slight degree. Water can be compressed so very little that practically it is regarded as incompressible.

37. **Influence of Heat on the Bulk of Liquids.**—Although the interstices between the particles of liquids can not be varied by mechanical pressure, they can be by variations of temperature. Liquids are dilated or expanded by heat; that is, their particles are put farther apart. They are contracted or compressed by cold; that is, their particles are brought nearer together by the abstraction of heat. The most familiar example that we have is in the thermometer. The mercury rises in the tube when the heat increases the interstices between its particles; and it falls when the loss of heat allows the particles to come near together. The same effects are seen when alcohol is used in the thermometer, as is done in the arctic regions, because mercury may freeze there. A thermometer with water in it would answer if we wished only to measure temperatures between the freezing point and the boiling point of water. The expansive influence of heat will be particularly treated of hereafter.

38. **Compressibility of Aeriform Substances.**—Aeriform bodies are more compressible than any other substances, showing that in their ordinary condition there is a great deal of space among their particles. While they are thus unlike liquids in compressibility, they are affected by heat in the same way that liquids are.

39. **Elasticity.**—Closely allied with the compressibility of matter is its elasticity. We see this property strikingly exemplified in India-rubber. It occasions the rebounding of a ball of this substance when thrown down. Observe now exactly what occurs in this case. The ball as it meets the resistance of the floor is flattened, as represented in Fig. 4. Then, as it assumes the round shape, as seen in Fig. 5, it pushes downward upon the floor. It is this sudden pushing down-

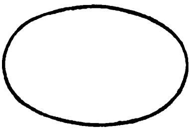

Fig. 4.

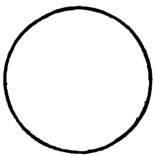

Fig. 5.

ward that makes it rebound. It is as if there were a compressed spring between the ball and floor. It may be likened also to jumping. When one jumps he bends his limbs at the thigh and knee joints, and then, in straightening himself up, gives a sudden push, like that given by the ball as it assumes its round shape, and so is thrown forward or upward, according to the direction in which the pushing force is made. The same flattening occurs in an ivory ball, though not to the same degree. You can prove that it does occur by experiment. Let a marble slab be wet and drop the ball upon it. Quite a spot will be made dry by the blow of the ball, showing that it touched more of the marble than it does when it is merely placed upon it.

40. **Elasticity Shown in Other Ways.**—If a stick be bent, as in Fig. 2, as soon as the bending force is withdrawn the stick becomes straight again from its elasticity. It is this elastic force of the bow, straightening it, that speeds the arrow. Observe in this case that while the particles on the concave side of the bent bow are brought nearer together or compressed, those on the convex side are moved apart. This moving apart of the particles is often shown in India-rubber. You can see how very far apart particles that are in near neighborhood may be carried, if you will stick two pins close together in a strip of India-rubber before you stretch it.

41. **Degrees of Elasticity in Different Substances.**—Some substances have so very little elasticity that they are practically considered as having none. Lead is one of these. A rod of lead when bent remains so, and a leaden ball does not rebound. While aeriform substances are the most compressible of all, they are also the most elastic. Air compressed returns to its usual condition the moment that it is relieved from the pressure, and with a force proportioned to the amount of the pressure. So it is with steam and the gases. The varied results of this quality of aeriform substances will claim our at-

tention more particularly in some other parts of this book.

42. **Definition of Elasticity.**—You see from the illustrations that have been given that elasticity is *that property of matter by which its particles, when brought nearer together or carried farther apart by any force, return to their usual condition when the force is withdrawn.*

43. **Usefulness of Variety in Properties of Matter.**—The various properties of matter brought to view in this chapter are providential adaptations to the necessities of man. Each substance has those properties which best fit it for his use. Iron, for example, designed by the Creator to be both the strongest and most extensively useful servant of man among the metals, is therefore provided in great abundance, and has those strong, decided, and various qualities which fit it for the services it is to perform. Gold and silver, on the other hand, designed for services less extensive, lighter, and in a great measure ornamental, are provided in very much less quantity, and have properties admirably adapting them to the services for which they are so manifestly intended. The same can be substantially said of all other substances, and especially of those very abundant ones, air and water. And it may be remarked also that the ingenuity of man is continually discovering new modes of bringing the various properties of matter into his service. I will give but a single illustration—the tempering of steel. "This discovery," says Dr. Arnot, "is perhaps second in importance to few discoveries which man has made; for it has given him all the edge-tools and cutting-instruments by which he now moulds every other substance to his wishes. A savage will work for twelve months with fire and sharp stones to fell a great tree and to give it the shape of a canoe, where a modern carpenter, with his tools, could accomplish the object in a day or two."

CHAPTER III.

THE ESSENTIAL PROPERTIES OF MATTER.

44. **Extension.**—You can not conceive of any portion of matter, however small it may be, that has not shape or figure. It may be so small as to appear only as a point to the naked eye, but seen through the microscope its shape becomes obvious. Even an atom must have length, breadth, and thickness, though it be so small that we can not measure it, nor see its shape with the most powerful microscopes. *Extension*, which is the term commonly used to express this idea, is then an *essential* property of matter; that is, it is a property of which no form or kind of matter can be destitute. The distinction, in this respect, between this property and those which I have before noticed may be made obvious to you by an example. Hardness is not an essential quality of matter, for some kinds of matter are destitute of it; but no portion of matter, hard or soft, can be destitute of extension or shape. The air is sometimes spoken of in common language as being shapeless. This is partly because it is invisible, and partly because no portion or body of air assumes any definite shape. But air is continually forced into definite shapes by confinement in rooms, boxes, etc.; and then its extension in different directions can be measured as accurately as the extension of a solid can be. And besides, the atoms of which air is composed are undoubtedly solid, and we can not conceive of their existence without attaching to them the idea of figure or extension.

45. **Impenetrability.**—In common language one substance is said to penetrate another. Thus a needle penetrates cloth, a nail penetrates wood, etc. But this is

not strictly true. The needle does not go into the cloth, but goes between the fibres of it, pushing them to the one side and the other. So the nail goes between the fibres of the wood, and not into them. It does not occupy the same room that the fibres do at the same time. So, also, no atom of matter can penetrate or go into any other atom. It can only push it out of the way, and then occupy its place. Impenetrability is therefore said to be one of the essential qualities of matter. This means simply that no portion of matter can occupy the same space with another portion of matter at the same time.

46. **Illustrations.**—Many illustrations might be given of this property. I will give a few. If you press a tumbler into water with its open end downward, you can not fill it with water, for the air confined in the tumbler prevents it from rising. It can not occupy the same space with the air. It fills, indeed, a portion of the tumbler, but this is because the air is compressible. If you introduce a glass funnel, *a*, Fig. 6, into a jar of water, *b*, with your thumb on its mouth, *c*, the water will not rise to fill it. But if you take your thumb off, the water will rise to the level of the water outside of the funnel, pushing up the air before it. If you have not a funnel, a vial or bottle with its bottom broken off will answer for the experiment. The following is a very pretty experiment, illustrating the same point. Place a lighted taper, *a*, Fig. 7, on a large flat cork in a jar of water. Put over it an open jar or receiver, *b*, having a stop-cock, *c*. Closing the stop-cock, press the receiver down into the water, and you will see the taper sink with it, as represented in the figure, the air preventing the water from entering the receiver. If now you open the stop-cock the water rushes in, thrusting the

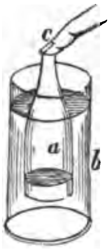

Fig. 6.

Fig. 7.

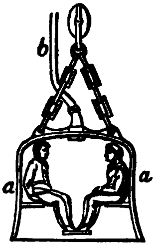

Fig. 8.

air upward, and making the taper to appear as if rising out of the water. The diving-bell offers a good illustration. It consists of a vessel, *a a*, Fig. 8, shaped like a bell, made sufficiently heavy to sink in water. It is let down by a chain and cable, as seen in the figure. The water does not enter the bell any farther than the compressibility of the air permits it. In order that the men in it may remain under water for some time fresh air is supplied by the tube *b*, it being forced down by a forcing-pump. At the same time the vitiated air can be let off by a valve provided for that purpose. There are windows in the top of the bell to give the requisite light for work on the sea's bottom. Treasures are often recovered by this means which would otherwise be lost. You see a resemblance between the diving-bell and the arrangement in Fig. 7, the receiver representing the bell and the lighted taper the men in it.

47. **Other Illustrations.**—If you drop a bullet into a tumbler of water it pushes the particles to the one side and the other, and occupies the room thus made. If you drop in several there is a manifest rise of the water, and you may drop in enough to make it overflow. The same thing is true of the finest needle dropped in the water—it does not penetrate it, but like the bullet displaces some of its particles and occupies their room; and you can make the water overflow by dropping in many needles. We can truly say, then, that water can not be penetrated even by a needle. When any substance, as sugar, is dissolved in water, its particles do not penetrate the water, but go into the spaces between its particles. So, also, when particles from odorous substances are diffused in the air, they are not really in the air, but are between its particles.

48. **Inertia.**—Matter has no power to put itself in mo-

tion. When it is moved it is moved by some force which is either outside of the matter or is communicated to it in some way. When your arm is moved it is not the matter in your arm that is the cause of its motion. It is caused by a force in you which I will not dwell upon here, because the subject belongs to Physiology. When air moves it is set in motion by some force acting upon it, as when you blow it from your lungs or move it with a fan. When the wind blows, the air is set in motion by heat and the attraction of the earth, as will be explained to you in another part of this book. I might multiply examples to any extent, showing that matter of itself can not move. This property of matter is termed *inertia.*

49. **Inertia Shown in the Inability of Matter to Stop its Motion.**—Matter, when once set in motion, has no power to stop itself. If it could stop itself it could not be said to be inert. And as it is inert, it would, when once set in motion, keep on moving forever unless stopped by some force. When a stone falls to the ground, it stops simply because the earth stops it. If the earth were not in the way, the stone would move straight on until it were stopped by something else. So, also, a stone that is thrown up in the air would keep on, and soon be out of sight, and never return to the earth, if it were not made to come down by forces acting upon it. One of these forces is the resistance of the air, which, from the moment the stone starts, is destroying its motion. Another force as constantly operating to retard the stone is the attraction, or drawing force, exerted by the earth upon it. This powerful though unseen force will be treated of fully in the next chapter.

50. **Matter Equally Inclined to Rest and Motion.**—It was formerly taught by philosophers that matter is more inclined to rest than to motion; and this is the popular notion now. This is because the chief causes that stop the motions that we see from day to day—viz., the air and the attraction of the earth—are not visible. For

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of attraction, for it is a mere result of attraction. Suffice it to state here, that the weight of a body is *the pressure occasioned by the attraction existing between it and another body*. If when a stone is raised from the ground the attraction between it and the earth could be destroyed, the stone would remain there. It would not

press down, and so would have no weight. It is plain, therefore, that weight, so far from being an essential property of matter, is not really a property at all. It is only an effect of a property—attraction. If there were only one body in the universe, it would have no weight, for it would press in no direction because there is nothing to attract it. But as it is, all matter has weight, for there is other matter to attract it.

CHAPTER IV.

ATTRACTION.

53. **Nature of Attraction.**—If you attempt to break a very tenacious solid substance, why do you not succeed? It is because the particles are so strongly fastened together. But how? By some kind of cement or glue, or by some mechanical contrivances as nails or hooks? No. They are fastened together by some unseen force. We know nothing of the nature of this force. We know only that it exists, and we call it attraction. The name is a proper one, for it simply expresses the fact that one particle attracts or draws another particle toward itself.

54. **Newton's Idea of Attraction.**—It was stated in § 20 that the particles of matter, even in the densest substances, are not in actual contact, but have spaces around them. Now it was supposed by Newton that there is some kind of ethereal substance pervading all these spaces, which causes this attraction between the particles. He supposed also that this ether was every where in space, causing attraction between masses of matter. But all this is mere supposition, and we know not whether there is this sort of ethereal glue keeping the universe together, or whether it is some property in the particles themselves that makes them thus attract each other. But the fact of the attraction we know, and we can observe the phe-

nomena which it produces, and discover the laws or rules by which this force is regulated in its action.

55. **Attraction in Solids.**—Attraction is stronger in some solids than in others. The mason with his trowel easily divides a brick; but he can not do this with a piece of granite, for its particles have a greater attraction for each other than those of the brick. So a rap which would break a glass dish would not injure a copper one of the same thickness. A weight that would hang securely from an iron wire would break a lead wire of the same size; that is, it would tear the particles apart, because they are not strongly attracted to each other. Attraction has different modes of action in different solids. It therefore fastens their particles together in different ways, and thus produces all the various qualities, already noticed, which are so useful to us—tenacity, hardness, softness, ductility, flexibility, etc.

56. **Attraction in Liquids.**—In a liquid the attraction between the particles is very feeble compared with that in solids. The attraction of the particles of steel is in strength about three million times that of the particles of water. We make the estimate in this way: We find that a steel wire will sustain a weight equal to 39,000 feet of the wire. But a drop of water hanging to the end of a stick can not be more than one-sixth of an inch in length; that is, water will hold together by the attraction of its particles only to this extent, which is a little less than the three millionth part of the length of steel wire which could hang without breaking.

57. **Freeness of Movement of the Particles of Liquids.**—There is one prominent characteristic of liquids which is probably not entirely owing to the feeble attraction of their particles—I mean the freeness with which these particles are moved among each other. This is owing probably in part to some peculiar arrangement of the atoms in making the particles of a liquid. I will illustrate this in a coarse way. If the atoms of lead in shot

were so arranged as to make irregular jagged forms, they could not readily be moved among each other. We suppose the ultimate atoms of a liquid to be so arranged in the formation of particles as to make them not only round but very smooth. Hence comes the great ease with which they circulate among each other.

58. **Globular Shape of Drops of Liquids.**—As the particles of a liquid move thus freely among each other, their attraction disposes them to assume a globular or round shape. The reason of this can be made plain by Figs. 9 and 10. The outside of a perfect sphere is all at the same distance from the centre. So all the circumference of a circle is at the same distance from the centre, as represented in Fig. 9. But this is not true of all parts of the surface of a cube or of a square: *a*, for example, is farther from the centre than *b* is.

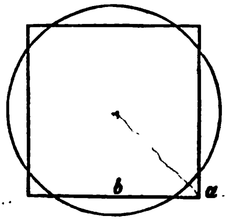


Fig. 9.

Now in a drop of liquid all the particles are attracted toward the centre, for in that line from each particle lies the largest number of particles to attract it. This can be made obvious by taking some point in the drop, as represented in Fig. 10; and drawing lines from it through the centre and in other directions. If *a* be the point in the drop, it is plain that the line from it through the centre is longer than *a b* or *a c*. Therefore a particle, *a*, will be attracted toward the centre rather than in the direction *a b* or *a c*, because there are more particles in the direction of the centre, and the more particles there are the stronger is the attraction. But this is not all. The particles in the line *a c*, tending to make *a* go toward *c*, are balanced by the particles in the line *a e*, tending to make it go to-

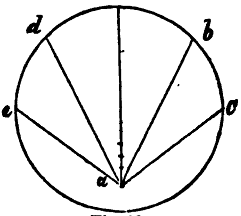


Fig. 10.

ward *e*. The two lines of particles therefore together tend to make it go in a middle line between them, that is, toward the centre, just as two strings pulling equally, the one to *c* and the other to *e*, would make a body, *a*, move in a middle line between these two directions. The same can be shown of the two lines of particles *a b* and *a d*, and so of any other two alike in situation on each side of the line through the centre. The tendency of every particle is, then, to go toward the centre, and it would go there if there were not particles between to prevent it. You see how this would operate in the case of the particles on the surface of the drop. As these are all striving, as we may say, in obedience to attraction, to get to the centre, none of them will be raised up into an angle or a point, as would be the case if the drop were in the shape of a cube. If this should be done it would show that some of the particles were not as strongly attracted toward the centre as others are, which is an impossibility.

59. **The Globular Form in Different Liquids.**—The disposition to form a sphere is seen more distinctly in mercury than in any other liquid. If you drop a little of it upon a plate it separates into globules, which roll about like shot. Why can not the same thing be done with water? Why do the drops of water hang upon the window-pane, showing only in an imperfect way their disposition to the globular arrangement? It is because the particles of water have a greater attraction for other substances, and less attraction for each other, than the particles of the quicksilver have. Water sometimes exhibits its disposition to the globular form in full on the leaves of some plants, and rolls about in balls like mercury. This is because there is something on the surface of the leaf which repels rather than attracts the water. If you put your finger, however, on one of these drops, it will spoil it, and your finger will be moistened, because there is an attraction between the particles of your skin

and of the water. Take another illustration of this difference in attraction. If you drop a little oil upon the surface of water it will float about in round drops. This is because the water repels the oil, as the surface of some kinds of leaves does water. But when oil is spilled upon wood or cloth its particles have so strong an attraction for their particles that they unite with them, instead of gathering up into little round companies as they do on the surface of water.

60. **Manufacture of Shot.**—We have a beautiful example of the tendency of fluids to the globular arrangement in the manufacture of shot. The melted lead is poured into a large vessel in the top of the shot-tower. This vessel has holes in its bottom, from which the metal falls in drops. Each drop, as it whirls round and round in its fall, takes the globular form. By the time that it reaches the end of its journey, about two hundred feet, it becomes so far cooled as to be solid, and as it is received in a reservoir of water, its globular form is retained. Bullets can not be made in this way, because a quantity of melted lead sufficient to make a bullet will not hold together in a globular form.

61. **Globular Form of the Earth and the Heavenly Bodies.**—It is supposed that the sun, moon, earth, and all the heavenly bodies were once in a liquid state, and that they owe their globular shape to this fact. As they whirled on in this condition in their course, the different solids were gradually formed, and at length they acquired their present state. How all the mighty changes could be effected in our earth, converting it from a liquid into a body with a solid crust, having such various substances in it, and so variously arranged, with its depressions containing water, and the whole covered with its robe of air fifty miles in thickness, we can not understand. And yet there are some portions of the process which chemistry and geology have revealed to us, giving us some glimpses of the wonders which, during the lapse of ages, God

wrought in our earth in preparing it for the habitation of man.

62. **Crystallization.**—The arrangement of the particles of solid substances is different from that of liquids. The tendency here is to straight lines and angles; that is, to crystalline forms. Alum or common salt, when it becomes solid from a solution, forms crystals. So also does sugar. The crystals of different substances are different. In Fig. 11 you have the crystal of common salt, and in Fig. 12 that of alum. We see this crystalline tendency every where, even in the rude rocks and common stones. The rocks are disposed to exhibit regular layers, or columns, or battlements, and always do so except when interfering circumstances prevent. And when you examine their composition, or that of the stone under your feet, you see the same crystalline disposition in detail that you see in the mass.

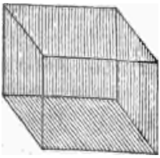


Fig. 11.

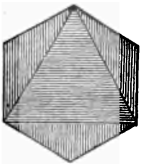


Fig. 12.

63. **Crystallization of Water.**—Water, when it changes into a solid, shows the same disposition, of which the crystals of the snow and the frost-work on our windows are familiar examples. When snow forms, the water of the clouds is suddenly crystallized by the cold air, the particles taking their regular places more readily and certainly than if they were guided by intelligence, because in obedience to an unerring law established by the Creator. We sometimes have an example of this sudden crystallization of water under our eye. The water in a pitcher may remain fluid, although it is cooled down to the freezing-point, and even below it, if it be kept perfectly still. But on taking up the pitcher the water at once becomes filled with a net-work of ice-crystals. The explanation is this: The stillness of the water has prevented its particles from taking on the new arrangement

needed for the formation of ice; but the jostling of them in taking up the pitcher has served to make them do it thus suddenly.

64. **Frost and Snow.**—The frost-work on our windows is a wonderful exhibition of the variety of forms that crystallization can produce. It sometimes presents figures like leaves and flowers, such as we see chased on vessels of silver, but much more delicate and beautiful. So varied and fantastic are the forms in which these water-crystals are arranged, that it is very natural to ascribe them, as is done universally in the dialect of the nursery, to the ingenuity of a strange and tricksy spirit. Every snow-flake is a bundle of little crystals as regular and beautiful as the crystals which you so much admire in a mineralogical cabinet. And there is great variety in the grouping of these crystals. You have some specimens of these groups in Fig. 13 as they appear on examining

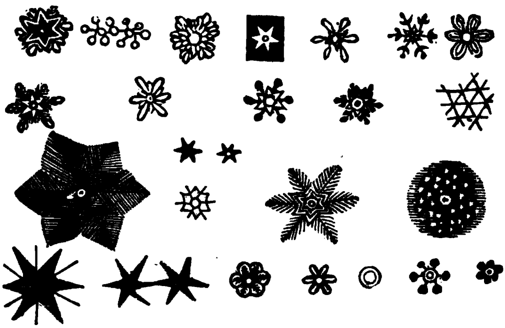


Fig. 13.

them with the microscope. Over six hundred different forms have been enumerated, and a hundred have been delineated. It is a very quick operation by which the particles of water in the clouds thus marshal themselves, as if by magic, in these regular forms. But a quicker operation is that by which hail is formed—so quick that the particles have not time to set themselves in the crys-

talline arrangement, but are huddled together without order. The brilliant and glistening whiteness of the snow is owing to the reflection of light from its minute crystals. In the arctic regions the beauty of the snow is often much greater than with us. "The snow crystals of last night," says Captain M'Clintock in his "Discovery of the Fate of Sir John Franklin," "were extremely beautiful. The largest kind is an inch in length; its form exactly resembles the end of a pointed feather. Stellar crystals two-tenths of an inch in diameter have also fallen; these have six points, and are the most exquisite things when seen under a microscope. In the sun, or even in moonlight, all these crystals glisten most brilliantly; and as our masts and rigging are abundantly covered with them, the *Fox* never was so gorgeously arrayed as she now appears."

65. **Order in Nature.**—We see in this general tendency to crystallization a striking illustration of the fact that God is a God of order. Disorderly arrangement is never seen except where there is an obvious necessity for it. And even when there is apparent disorder, a little examination generally shows that essentially there is order. The rocks that give so much variety to scenery are not piled up in confusion, and order has evidently reigned in their construction. Pick up a common stone, and on breaking it you will see the crystalline arrangement in its interior. Nay, more, much of the very soil is made up of separated and broken crystals.

66. **Particles Must be very Near to Each Other to Adhere.**—Why is it that when you have broken any thing made of glass, however accurately you may bring the two parts together, you can not make them unite in one again? It is simply because the particles of substances will not attract each other enough to be united unless they are brought very near together. Now it is impossible to bring the particles on the two surfaces of a broken piece of glass as near together as they were before it was

broken. If you could do so, no crack would be visible. You can join them by some kind of cement. This is because the particles of the cement, while it is soft, can be insinuated among the particles of the glass; and thus, when it dries, it becomes a bond of union between the particles on each side of the breach. For the same reason you can make the cut surfaces of some yielding substances adhere. If you divide a piece of India-rubber with a clean cut, you can make the two surfaces adhere by pressing them together firmly. The particles in this case are not unyielding, as those of the glass are, and some of them are therefore brought into such near neighborhood as to attract each other sufficiently to unite together. So, too, if you cut two bullets so as to have a very smooth flat surface on each, you can make them adhere quite strongly by pressing them together, especially if you give a little turning motion at the same time that you press, for this will cause the particles on the two surfaces to be somewhat mingled together. If you have

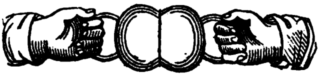


Fig. 14.

quite large balls of lead with handles, as represented in Fig. 14, it will require considerable force to separate them when they have been thus pressed together.

67. **Other Illustrations.**—Silver and gold may be made to adhere to iron by a very great and sudden pressure. The iron must be made very smooth, and the silver or gold plate very thin. A powerful blow brings the particles of the thin plate into such nearness to those of the iron that union is effected, or, in other words, that they attract each other sufficiently to be united. So, also, a sheet of tin and one of lead can be made to adhere so as to form one sheet by the pressure of the rollers of a flatting-mill. Two very smooth panes of glass laid one upon another may have so many particles brought into great nearness as to occasion some adhesion. It will be slight, however, few comparatively of all the particles coming

near enough to adhere, for the smoothest glass is full of inequalities, as may be seen by the microscope.

68. **Strength of Adhesion.**—In no case do particles come in actual contact (§ 20), and their adhesion depends on the nearness of their neighborhood to each other. The strength of union, then, between two surfaces depends on the number of particles brought near enough to adhere together. In the case of the two bullets or the lead balls, if all the particles of the two surfaces were near enough to adhere, the lead would be just as strong at the junction as any where else. The reason that so strong adhesion takes place between portions of some substances when we soften them by heat is that the particles of the two softened ends are all brought near enough together for adhesion. Thus the two ends of a broken stick of sealing-wax may be firmly united by heating them and then pressing them together. The same thing can be done with glass. When iron is welded, as it is termed, some hammering is required to make the particles of the two softened ends of the iron unite.

69. **Attraction Between Solids and Liquids.**—The attraction which solids and liquids have for each other furnishes us with many interesting phenomena. The adhesion of drops of water to glass and other solids is a familiar example of this attraction. If you dip your hand into water, it is wet on taking it out, because your skin has sufficient attraction for the water to retain some of it. A towel will retain more of it for two reasons—with the interstices between its fibres it presents much more surface to the water, and it has none of the oily substance which on your skin, though being in small quantity, serves somewhat to repel the water. The attraction of solids and fluids for each other is shown very prettily in the experi-

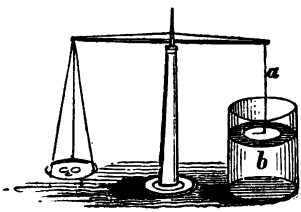


Fig. 15.

ment represented in Fig. 15 (p. 47). A piece of wood is attached by the string, *a*, to one end of a balance, and weights just sufficient to balance it are placed in the opposite scale. If now the wood is brought in contact with the water in the vessel, *b*, it will require additional weight in the scale to separate the wood from the water.

70. **Farther Illustrations.**—When you see stems of plants rising above the surface of stagnant water you will observe that the water is considerably raised about them. This is from the attraction between them and the water. For the same reason water is not as high in the middle of a tumbler as it is at the sides. If you immerse a piece of glass in water, the water will rise at its sides as represented in Fig. 16. If you immerse two together,

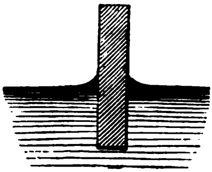


Fig. 16.

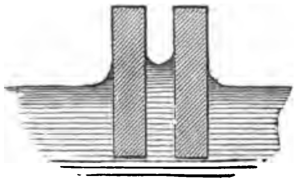


Fig. 17.

as in Fig. 17, the water will rise higher between than outside of them, because the particles between are attracted by two surfaces, while those outside are attracted only by one. It is for the same reason that two men can raise a weight higher than one of them can alone. And if the pieces of glass be brought quite near together, as in Fig. 18, the water will be raised higher still, because there is less to be raised by the two surfaces. It is just as two men can raise a small weight higher than they can a large one. The same thing may be beautifully illustrated in this way: Let two pieces of

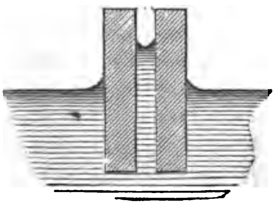


Fig. 18.

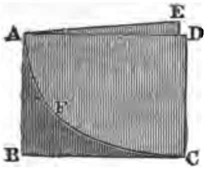
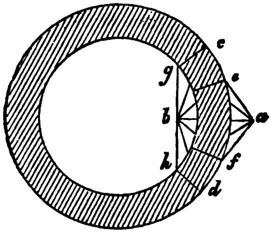


Fig. 19.

glass, as represented in Fig. 19, be immersed in colored water, with two of their edges joined together at A B, the opposite edges at E D C being separated. The height to which the fluid rises will make a curved line, A F C, it being lowest at the edges which are separated, and highest at the edges which are joined together.

71. **Rise of Liquids in Tubes.**—For the same reason that water rises higher between plates of glass than outside, so it will rise higher in a tube than it will outside of it. The diagram in Fig. 20 will make this clear. I represent in this a transverse section of a tube, enlarged so that the demonstration may be plain. We will take a particle on the inside and the outside at equal distances from the glass. It is clear that the particle *a* is not as near to as many particles of the glass as the particle *b* is. The lines drawn show this. The longest lines extending from the particles *a* and *b* to the glass are equal in length; that is, *a e* and *a f* are equal to *b g* and *b h*. It is clear, therefore, that all the glass between the lines at *c* and *d* is as near to the particle *b* as the glass between the lines at *e* and *f* is to the particle *a*. But this is not all. The particle *b* is near enough to all the inside of the tube to be attracted by it, while very little attraction is exerted upon *a* by any part of the glass beyond that which is included between *e* and *f*. The same difference can be shown with regard to all the particles on the inside of the tube compared with those outside. The former are nearer to more particles of the glass than the latter, and therefore are more strongly attracted. Again, as the



nearer the plates of glass are (§ 70) the higher the water rises between them, so the smaller the tube is the higher will the water rise in it. You can try the experiment as represented in Fig. 21. It is obvious that the particle *b* (Fig. 20) would not be very strongly attracted by the part of the tube opposite if the tube were a large one; but it would be if the tube were very small, for then it would be quite near to that part.

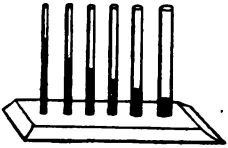


Fig. 21.

72. **Capillary Attraction.**—The term capillary (derived from the Latin word *capilla*, hair) has been commonly applied to the attraction exhibited under the circumstances just noticed, because it is most obvious and was first observed in tubes of very fine bore. The same term is used when the attraction is seen in the rising or spreading of a liquid in interstices as well as in tubes. Thus capillary attraction causes the rising of oil or burning fluid in the wicks of lamps. The liquid goes up in the interstices or spaces between the fibres, as it does in the spaces of tubes. I will give some other examples. If you let one end of a towel be in a bowl of water, the other end lying over upon the table, the whole towel will become wet from the spreading of the water among the fibres in obedience to capillary attraction. If you suspend a piece of sponge so that it merely touch the surface of some water, or if you lay it in a plate with water in it, the whole sponge will become wet. So, too, if you dip the end of a lump of sugar in your tea, and hold it there a little time, the whole will be moistened. In very damp weather the wood-work in our houses swells from the spreading of water in the pores of the wood in obedience to capillary attraction. Especially will this be so in basement rooms, where the water can go up from the ground in the pores of the walls, as well as from the damp air. In watering plants in pots, if the

water be poured into the saucers, it will pass up through the earth by capillary attraction. For the same reason plants and trees near streams grow luxuriantly, being abundantly supplied with water, which rises to their roots through the pores of the soil. The disposition of wood to imbibe moisture in its pores has sometimes been made use of very effectually in getting out millstones. First a large block of stone is hewn into a cylindrical shape. Then grooves are cut into it all around where a separation is desired, and wooden wedges are driven tightly into them. These absorb moisture from the dews and rain, and therefore swell so much as to split the stone in the direction of the grooves. The blotter which you use furnishes an illustration of capillary attraction, the ink being taken up among the fibres of the paper. Ordinary writing paper will not answer as a blotter, because the sizing fills up the interstices between the fibres.

CHAPTER V.

GRAVITATION.

73. **Attraction Between Masses.**—I have thus far treated of attraction as existing between the atoms or particles of matter when they are brought very near together, which is called the attraction of *cohesion*. But it exists also between any portions of matter that are separate from each other. Thus if two cork balls be placed on the surface of water near to each other, their attraction will soon bring them together. To have the experiment striking, the balls must be varnished, that they may glide easily over the water. Bubbles of glass will exhibit the same attraction. So, also, floating pieces of wood are apt to be found together; and when a ship is wrecked, as soon as the sea becomes calm the parts of

the wreck are in collections here and there. Now when a stone falls to the ground, it does so for precisely the same reason that the two cork balls come together in the water. The idea of all who have not been informed on such subjects is, that the stone comes to the ground because the ground is down and the stone is up, and there is nothing to support the stone in the air. They have no idea that some power makes the stone come down. There is such a power, and it is the attraction which the earth and the stone have for each other. If you hold the stone in your hand, and thus prevent its falling, you simply resist a power which is pulling it down. If you could in any way suspend the attraction of the earth and the stone for each other, you could let go of the stone, and it would remain just there in the air, and would not come down until the attraction is restored.

74. **Attraction Mutual.**—The cork balls move toward each other because their attraction is mutual. So do the earth and stone really move toward each other for the same reason. As the stone is drawn toward the earth, so is the earth drawn toward the stone. But the earth is so large a thing to be drawn that its motion is exceedingly small—so small that practically it may be considered as nothing.

75. **Illustration.**—This may be clearly illustrated if we compare the force of attraction to the force of muscular action. Suppose a man in a boat pulls on a rope which is made fast to a ship lying loose at the wharf, and in this way draws his boat toward it. He does not dream that he moves the ship at all; but he in reality does, for if instead of one boat a hundred or more pull upon the ship, they will move it so much as to make the motion apparent. In the case of the single boat, the ship as really moves as when a hundred boats are pulling on it, but it is only the one hundredth part as much. Now let the ship represent the earth, and the little boat some body, as a stone, attracted by it. The earth and the

stone move toward each other, just as the ship and the boat do. And if, as we multiplied the number of boats, we should multiply the bulk of the stone till it is of an immense size, it would have by its attraction a perceptible influence upon the earth's motion.

Observe in regard to the illustration, that it makes no difference whether the man be in the boat or in the ship as he pulls. In either case he exerts an equal force on the ship and the boat, making them to approach each other. So it is with the attraction between the earth and the stone. It is a force exerted equally upon both. Its effect on the earth is not manifest, because it is so much larger than the stone; just as the effect of the man's pulling is not manifest upon the ship, because it is so much larger than the boat.

76. **Proportion of the Mutual Motions of Attraction.**—Let us pursue the illustration a little farther. If a man stand in a boat, and pull a rope made fast to another boat of the same size and weight, both boats, in coming together, will move over the same space. Just so it is with the attraction between two bodies having the same quantities of matter or equal weights—they attract each other equally, and therefore meet each other half way. Let now one boat be ten times as great and as heavy as the other. The small boat would move ten times as much as the large one when the man brings them together by pulling the rope. In like manner, if a body one-tenth as large as the earth should approach it, they would attract each other, but in coming together the body would move ten times as far as the earth would. In the case of falling bodies, even though they may be of great size, the earth moves so slightly to meet them that its motion is wholly imperceptible. It has been calculated that if a ball of earth the tenth part of a mile in diameter were placed at the distance of a tenth part of a mile from the earth, as the earth and this body would be moved by their attraction to meet each other, the mo-

tion of the earth would be only the eighty thousandth of a millionth ($\frac{1}{80,000,000,000}$) of an inch.

77. **Attraction Universal.**—The attraction of which I have been speaking exists between all bodies, however distant they may be from each other. Sun, earth, moon, and stars attract each other; and in obedience to this attraction they have a tendency to come together in one great mass, and would do so if another force acting in opposition to this did not prevent it. This force will be treated of in another part of this book.

78. **The Tides.**—One effect of the attraction between the earth and the moon is quite familiar. I refer to the tides. When the tide rises it is because the water of the ocean feels the attracting force of the moon. The moon actually lifts the water toward itself. The attraction of the sun sometimes increases and sometimes diminishes the tides, according to its position in relation to the moon and the earth. If the land were as movable as the water, or, in other words, if its particles were held together by no stronger attraction than those of water, there would be the same motion that there is in the ocean over the surface of the earth, as in its revolution successive portions of it present themselves toward the moon.

79. **Meaning of the Word Gravitation.**—The attraction thus existing between different bodies of matter separated from each other is called the attraction of gravitation or gravity, in distinction from the attraction of *cohesion* treated of in the previous chapter. This name was given to it because we have such common examples of its influence in the fall of bodies to the earth. They are said to *gravitate* toward the earth. And they are said to do so by the force or attraction of gravitation or gravity. The term *terrestrial* gravitation is sometimes used in speaking of the earth's attraction, in distinction from the same thing in operation in other planets.

80. **Attraction Toward the Earth's Centre.**—All bodies

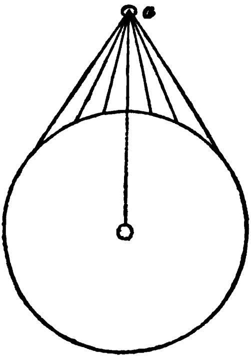


Fig. 22.

are attracted toward the centre of the earth. This is because the earth is globular, as may be made clear by Fig. 22. Let the circle represent the earth, and *a* a body attracted by it. The lines drawn from the body to the earth represent the attractive force exerted by the earth upon the body. It is obvious from these that there is as much attraction on the one side of the line drawn from the body to the earth's centre as there is on the other. The attractive force, then, of the earth as a whole is exerted upon the body in the direction of this middle line. It tends to draw it, therefore, toward the centre. If, therefore, a weight be suspended by a string, the line of the string continued would go to the centre of the earth. This being so, it is clear that two weights suspended by two strings do not hang perfectly parallel to each other. The difference is so slight in an ordinary pair of scales that it can not in any way be perceived. But if it were possible to suspend in the heavens a beam so long as to stretch over a large extent of the earth's circumference, as represented in Fig. 23, the scales attached to it would be very far from hanging parallel to each other. Substances suspended in different parts of the globe are hanging in different directions, and those which are hung up by our fellow-men on the opposite side of the earth are hanging directly toward us.

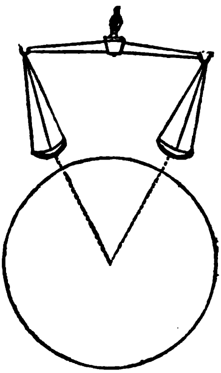


Fig. 23.

81. **Up and Down.**—All falling bodies fall toward the

centre of the earth, and the same remarks can be made on this point that I have made in relation to suspended weights. Up and down are merely relative terms—*up* being from the centre of the earth, and *down* toward it.

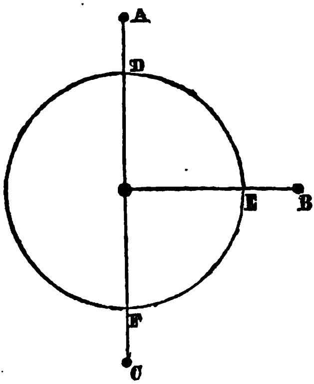


Fig. 24.

As the earth moves round on its axis, the same line of direction which we call upward at one time is downward at another. This may be illustrated on Fig. 24. Let the circle represent the circumference of the earth. In the daily revolution we pass over this whole circle. If we are at D at noon, we are at E at six o'clock, and at F at midnight. If, therefore, the ball A be dropped from some height at noon, the line in which it falls will be at right angles to a line in which it will fall if you drop it from the same height at six o'clock; for this height will have moved in this time from A to B. If it be dropped from the same height at midnight its line of direction will be directly opposite to what it was twelve hours before; for the height will have moved in that time to C.

It is not always true that falling bodies tend exactly toward the centre of the earth. It is nothing in the centre that attracts them, but it is the substance of the whole earth; and as this is irregular in its density and form, the attraction will be irregular also. Thus it is found by accurate experimenting that a plumb line suspended in the neighborhood of a mountain is so attracted by it that it will not hang exactly parallel with another suspended at some distance from the mountain. The difference is not, however, enough in any case to have any practical bearing.

82. **Weight.**—I have said before (§ 52) that what we call weight is not a property of matter, but merely the result of a property, the attraction of gravity. This I will now illustrate. If two bodies are falling to the earth, and one of them contains ten times as many particles of matter as the other, ten times as much force of gravity is required, and is actually exerted, to bring it to the ground. This will appear plain to you if you bear in mind that a body does not come to the ground because there is nothing to keep it there, but because it is drawn down by the force of attraction, and then compare this force to any other force, as, for example, that of muscular action. If you draw toward you two weights, one of which is twenty times as heavy as the other, or, in other words, has twenty times the quantity of matter that the other has, you must exert twenty times as much strength on the former as you do on the latter. Just so it is with the force of attraction. The earth attracts or draws toward itself a body having twenty times the quantity of matter that another has with twenty times the amount of force. And the first body will have twenty times the weight of the other, for it will make twenty times the pressure upon any thing that resists the force with which the earth draws it toward itself. Weight, then, is *the amount of the pressure occasioned by the attraction existing between the earth and the body weighed.* If you place a substance in one side of a pair of scales, it goes down because of the attraction between it and the earth. By placing weights in the other side until the scales are balanced, you find how much is needed to counteract the downward pressure caused by the attraction of the substance and the earth for each other; or, in other words, you find out how much it weighs. In doing this you use certain standard weights; that is, certain quantities of matter which have been agreed upon by mankind, and are called by certain names, as pounds, ounces, etc. When a spring is used in weighing, the spring has been tried

by these standard weights, and its scale has been marked accordingly.

83. **Weight not Fixed, but Variable.**—Weight does not depend alone upon the density of the body weighed, but also upon the density of the earth. For the attraction causing the pressure which we call weight is a *mutual* attraction, and is in proportion to the quantities of matter in both the body and the earth. If, therefore, the density of the earth were increased twice, three times, or four times, the weights of all bodies would be increased in the same proportion; that is, the force with which the earth would attract them would be twice, three times, or four times as great as now. This would not be perceived by any effect on balances, for the weights and the articles weighed would be alike increased in weight. But it would be perceived in instruments that indicate the weights of bodies by their influence on a spring. These would disagree with scales and steelyards just in proportion to the increase of the earth's density. It would be perceived also in the application of muscular and other forces in raising and sustaining weights. Every stone would require twice, three times, or four times the muscular effort to raise it that it does now.

84. **Weight Varies with Distance.**—The nearer two bodies are to each other the greater is their attraction. The nearer a body is to the earth the greater is the attraction that presses it toward the earth; in other words, the greater is its weight. The force of gravity, or weight, is greatest, therefore, just at the surface of the earth, and it diminishes as we go up from the earth. As we go from the earth, the force of gravity lessens in such a proportion that it is always *inversely* as the square of the distance from the centre of the earth. I will explain. If the distance from the centre of the earth to its surface, which is 4000 miles, be called 1, then 4000 miles from the earth would be called 2, or twice as far from the centre, and 8000 miles from the earth would be 3, and so on.

The squares of these numbers would be 1, 4, 9, 16, etc. Now as weight lessens so as to be *inversely* as the square of the distance, a body weighing a pound on the surface of the earth would weigh but a quarter of a pound at the distance of 4000 miles, and but the ninth part of a pound at 8000 miles. A body weighs less on the summit of a high mountain than it would in the valley below, because it is farther away from the great bulk of the earth, and therefore is not so strongly attracted. The difference, however, is but small. A man weighing two hundred and fifty pounds in the valley would weigh but half a pound less if on the summit of a mountain four miles high.

85. **Weight Every Where.**—I have spoken of weight only in relation to the earth. But there is weight in bodies every where, for there is attraction wherever there is matter. The weight of substances on the surface of different heavenly bodies varies according to the quantities of matter in those bodies. As the moon is much smaller than the earth, what weighs a pound with us would weigh much less than a pound in the moon. And as the sun is much larger than the earth, what is a pound with us would be much more than a pound there. If we knew the exact densities of the sun and the moon and the earth, as well as their size, we could estimate exactly the difference in the weights which any body would have in them; for the attraction which causes the pressure that we call weight is as the quantity of matter, and the quantity of matter depends on both density and size.

86. **Cohesion, Capillary Attraction, and Gravitation the Same.**—The attraction of cohesion, capillary attraction, and gravitation are only different modes of action of the same power; viz., the attraction which matter every where has for matter. At first thought it would appear that there is something peculiar in the attraction of particles when they are brought together so as to adhere. For if we take any substance, a piece of glass, for exam-

ple, its particles seem to be held together by an attraction vastly stronger than that attraction which inclines different bodies to move toward each other. If you break the glass, however closely you may press the two pieces together, they will not unite again. It would seem, at first view, that there must be some peculiar arrangement of the particles which is destroyed by breaking the glass. But we can readily account for the facts in another way. The attraction between bodies of matter is the greater the nearer we bring them together. The nearer, for example, is the moon to any portion of the earth, the greater is the attraction which it exerts, as seen in the tides; and if it were much nearer to the earth than it is, our tides would prove awfully destructive. What is true of masses is also true of the particles of which they are composed. Though their attraction is comparatively feeble when at a distance from each other, it increases, not in the arithmetical but the geometrical ratio (§ 84), as they come nearer together; so that when they are exceedingly near together the attraction is very powerful. It must be remembered in regard to the pieces of broken glass that you can not bring the particles on their surfaces as near as they were before the glass was broken, for the crack does not disappear. And as the attraction is inversely as the square of the distance, a little distance must make a great difference. The particles of some substances you can bring so near together as to cause adhesion, as you saw in the case of the two bullets (§ 66). That their adhering together depends merely upon their particles being brought near to each other appears from the fact, that the smoother you make the surfaces the more strongly will they adhere. And the reason that liquids and semi-liquids adhere so readily to solid substances is, that their particles, moving freely among each other, have thus the power of arranging themselves very near to the particles of the solid. Thus, when a drop of water hangs to glass, all the particles of water in that

part of the drop next to the glass touch, or rather are exceedingly near to, the particles of the glass.

87. **Variety in the Results of Attraction.**—It is one and the same force, then, which binds the particles of a pebble together, and makes it fall to the ground—which "moulds the tear" and "bids it trickle from its source" —which gives the earth and all the heavenly bodies their globular shape, and, in connection with another power hereafter to be noticed, makes them revolve in their orbits. How sublime the thought that this one simple principle that gives form to a drop extends its influence through the immensity of space, and so marshals "the host of heaven" that, without the least interruption or discord, they all hold on their course from year to year and from age to age! It is thus that Omnipotence makes the simplest means to produce the grandest and most multiform results.

88. **Opposition Between the Modes of Attraction.**—Although cohesion and gravitation are essentially the same thing, we see them continually acting in opposition to each other. Abundant illustrations might be given, but I will cite only a few.

89. **Why Pitchers have Lips.**—If you pour water out of a tumbler there is a struggle between the attraction of cohesion and gravitation for the mastery—the attraction of cohesion tending to make the water adhere to the tumbler, and run down its side, as in Fig. 25, and gravitation tending to make it fall straight down. But when water is poured out of a pitcher, as in Fig. 26, the lip of the pitcher acts in favor of the attraction of gravity; for the water would have to turn a very

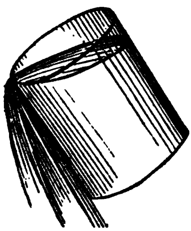


Fig. 25.

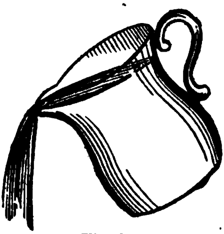


Fig. 26.

sharp corner to run down the outside of the pitcher in obedience to the attraction of cohesion. In pouring water from a tumbler, we can often, by a quick movement, throw the water, as we may say, into the hands of gravity before the attraction of cohesion can get a chance to turn it down the tumbler's side. If you can only make the water *begin* to run from the tumbler without going down its side there will be no difficulty; for there is an attraction of cohesion between the particles of the water, tending to make them keep together, which in this case acts against the cohesion between the water and the glass, and therefore acts in favor of gravitation. It is cohesion that forms the drop on the lip of a vial as we drop medicine—cohesion between the particles of the liquid, and cohesion between these particles and those of the glass. It is gravitation, on the other hand, that makes the drop fall, it becoming so large that the force of gravity overcomes the cohesion between the drop and the vial.

90. **Size Limited by Gravity.**—Were it not for the attraction of gravity there would be no limit to the size of drops of any liquid. When the drop reaches a certain size, it falls because it is so heavy; or, in other words, because with its slight cohesion the attraction of the earth brings it down. Now if this attraction could be suspended, and the attraction of cohesion left to act alone, particles of water might be added to the drop to any extent, and they would cling there. You can see the struggling between cohesion and gravitation very prettily illustrated if you watch the drops of rain on a window-pane. If two drops happen to be quite near together they unite by attraction, and then, being too large to allow of its being retained there by cohesion in opposition to gravitation, the united drop runs down. If it meet with no other drop it soon stops, because by cohesion some portion of it clings to the glass all along its track, and so at length lessens it sufficiently to allow it

to remain suspended again. It is from the influence of the attraction of gravitation that different kinds of liquids furnish drops of different sizes, the heavier giving small, and the lighter large ones. Thus you can drop from a vial a larger drop of alcohol than of water, and a larger one of water than of nitric acid. You have another illustration of a similar character in the adhesion of chalk to a black-board or any surface. The chalk crayon itself can not adhere, for the attraction of the earth does not permit it. But small quantities of it can adhere for the same reason that water adheres to surfaces in small quantities. So also dust clings to sides of furniture, though a lump of dirt would not.

91. **Illustrated in Solid Bodies.**—We can illustrate the limitation of size in solid masses by Figs. 27 and 28. Suppose that *a* and *b*, Fig. 27, are two projections of timber from a post, *b* being twice as large as *a*. It is evident that *b* can not support twice as much weight as *a*, for gravitation is dragging it downward from its attachment to the upright post with twice the force that it does *a*. The case is still stronger when, as represented in Fig. 28 (p. 64), the larger timber is twice as long as the smaller. Here *d* has four times the bulk of *c*. But it can not support four times as much weight at its end, not only because its own weight presses it downward, but because half of its weight is at a greater distance from the place of attachment than the smaller beam is. Gravitation here operates in opposition to cohesion in such a way that the projecting timber, if carried to a certain size, will fall by its own weight, either breaking in two, or tearing away from its attachment. This tendency is very commonly

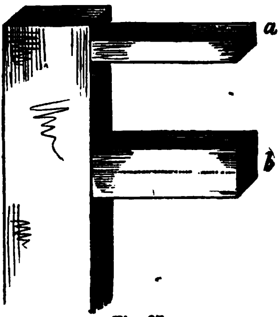


Fig. 27.

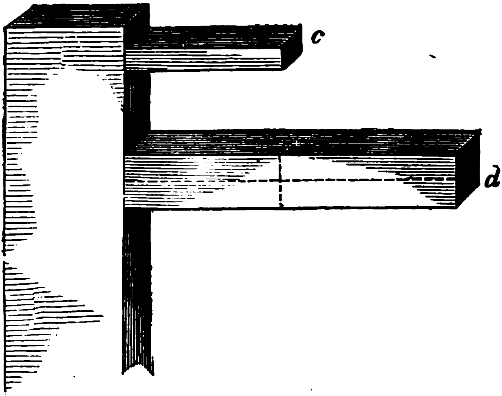


Fig. 28.

resisted in buildings and other structures by braces, as represented in Fig. 29. Here the weight of the horizontal timber at some distance on each side of *a*, is made to press upon the upright post instead of directly downward.

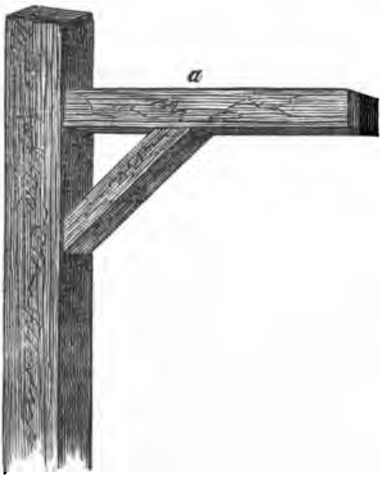


Fig. 29.

92. **Farther Illustrations.** — The size of bodies, both animate and inanimate, is limited by the Creator in obedience to the principles above developed. This is seen in the fact that there are no animals on the land to compare in size with the monsters of the deep. A whale does very well in the water, because he is buoyed up by that element; but an

animal as large as a whale could not well exist on land, because gravitation would act so strongly in opposition to cohesion. At least it would be necessary, in order that he might walk about, or even hold together, that his great bulk should be made up of very firm and tenacious materials. Whenever any thing very large or tall is to be supported, its support is always broad and composed of very cohesive materials. We see this exemplified in the massive trunks of full-grown trees, as compared with the slender trunks of trees of the same kinds in the nursery. We see it exemplified in the fact that the highest mountains are built of the hardest rocks, while the soft chalk formations are confined to those of small size. There is a limit to the height even of the granite mountains in the influence of gravity. If carried much higher than they are, the attraction of the earth, in its opposition to cohesion, would tear them apart in their fissures, or cause the immense weight to crush their foundations. In the moon, where gravitation is less than on the earth (§ 85), mountains can be much higher without these results, and accordingly the telescope shows them to be so. In Jupiter, on the other hand, which is much larger than the earth, the mountains, if there be any, can not rise to any great height, and if there be any living beings as large as we are in that planet they must be made of vastly firmer materials to prevent their being crushed by their own weight.

93. **The Above Principles Transgressed by Man.**—Man often transgresses these principles in his structures. For example, a building settles because the foundation is not strong enough to bear the superincumbent weight; in other words, the force of gravitation is not sufficiently taken into the account. When a very tall building is erected, the lower portions ought to be made of very cohesive substances. Firm granite is therefore an appropriate material for the lower story of tall brick buildings. At least should the walls of the lower stories of such

buildings be made thicker than they ordinarily are, to resist properly the force of gravitation in the weight above. Stores intended to bear much weight on their floors are often built without due regard to the cohesive force required to sustain the weight. Long timbers are sometimes supported only at the ends, when their own weight, to say nothing of what may be brought to press upon them, requires that they should be supported at other points. While in modern buildings the timbers are often too small, in some old buildings the upper timbers are so heavy as to lessen rather than increase the strength of the structure. Especially is this true of the unsightly beams which in some ancient houses we see extending along the ceilings above. Many other examples could be given, but these will suffice.

The practiced eye, in looking at a building, instinctively requires that every part should be *seen* to be suitably supported. A gallery in a church, therefore, if without pillars or braces from the wall, is displeasing to such an eye, even though there may be really sufficient support provided in the mode of structure. The same can be said of galleries supported by slender iron pillars, especially if they be painted of some light color so as to look as if they were wood rather than iron. For the same reason porticoes without pillars are unsightly. So, too, the eye instinctively looks for a sufficient base to every pillar and pilaster. The concealment of the base in any way, or the substitution of any thing else for it, is an unpleasant anomaly, and yet such anomalies are sometimes seen even in expensive buildings.

94. **Attraction of Natural Philosophy and of Chemistry.** —The attraction of which I have treated in this and the previous chapters is that which belongs to Natural Philosophy, in distinction from that of Chemistry. Its effects are only mechanical, while the attraction of Chemistry goes beyond this, and affects the *composition* of substances. For example, the attraction between the

two gases, oxygen and hydrogen, which makes them unite to form water, belongs to Chemistry; while that which makes the particles of water cohere is in the province of Natural Philosophy.

CHAPTER VI.

CENTRE OF GRAVITY.

95. **Centre of Gravity Illustrated.**—If you balance a ruler on your finger, as in Fig. 30, it is balanced because there is just as much weight on one side as on the other. Now just over your finger, in the middle of the ruler, there is a point that we call the centre of gravity; or, in other words, the centre of the weight of the ruler. This point is indicated in the figure. There is as much of the weight of the ruler on the one side of this point as on the other, and also as much above it as below it. If your finger should be a little to the one side or the other of this point, the ruler would not be balanced, and would fall. When balanced it does not fall, simply because this central point is supported by being directly over the end of the finger. The weight of the ruler, then, may be considered practically as all being in that point, for it is there that is exerted all the downward pressure of the ruler as it is balanced. So, also, when the ruler is balanced on the finger, as represented in Fig. 31 (p. 68), this same centre of gravity is directly over the point of the finger, and is therefore supported.

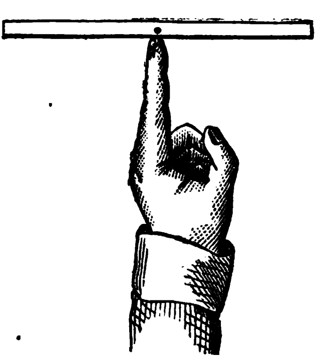


Fig. 30.

Fig. 31.

Fig. 32.

If it be to the one side or the other, as in Fig. 32, it is not supported, and the ruler therefore falls. You see, then, that if a body be balanced, the centre of gravity is directly *over* the point of support. If, on the other hand, a body is suspended, the centre of gravity is directly *under* the point of support.

96. **Definition.**—If a plumb-line from the centre of gravity could be extended into the earth it would go directly to its centre. The body may be considered as making all its pressure from its centre of gravity in that direction, in obedience to the attraction of gravitation. The best definition, then, that we can give of the centre of gravity is, that it is *that point in a body from which its pressure as a whole toward the centre of the earth proceeds.* It is that point, therefore, the support of which insures the support of the whole body. And in speaking of the weight of a body, or its downward pressure, we may consider all the matter composing it as collected or concentrated in that point. The body, therefore, can be balanced in any position in which this point is supported, as shown in Figs. 30 and 31. And when a body is suspended, it is at rest only when the centre of gravity is directly under the point of support. Thus, if you have a circular plate suspended at E, Fig. 33, it will not be at rest when it is moved to the one side or the other, as represented

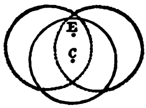


Fig. 33.

by the dotted lines, but only when the centre of gravity, *c*, is directly under the point E.

97. **How to Find the Centre of Gravity of a Body.**—If you take a piece of board, and suspend it at A, Fig. 34,

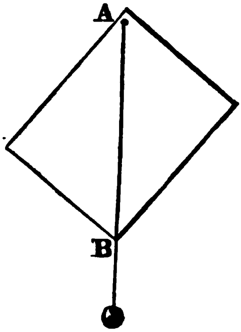


Fig. 34.

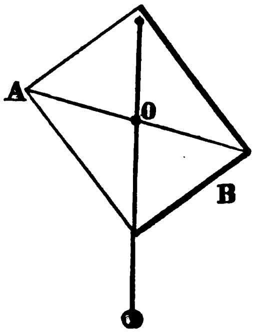


Fig. 35.

and suspend a plumb-line from the same point, the centre must be somewhere in that line. But exactly at what point it is you do not know. How will you ascertain this? Mark the line A B on the board, and suspend the board by another point, as in Fig. 35. As the centre of gravity must be somewhere in the plumb-line as it now hangs, of course it is at O, where the two lines cross.

98. **Scales and Steelyards.**—When two bodies are connected by a rod or bar, the centre of gravity of the whole is somewhere in the connection. If the two bodies be equal in weight, as in Fig. 36, the centre of gravity is

Fig. 36.

Fig. 37.

exactly in the middle of the rod, as marked. But if the bodies are unequal, as in Fig. 37, the centre of gravity is nearer to the larger body than to the smaller. In balancing a body in one scale with weights in another, you have a case parallel to that of Fig. 36. The centre of

gravity of the body weighed, the weights, and the scales, as a whole, is midway between the scales, at the point of support. In the steelyard you have the heavy body to be weighed nearer the centre of gravity than the small weight is on the long arm, and so the case is parallel with that of Fig. 37.

99. **The Centre of Gravity of a Body not Always in the Body Itself.**—The centre of gravity of a hollow ball of uniform thickness is not in the substance of the ball, but it is in the centre of the space in the ball, for the line of the ball's downward pressure would be from that point. If the ball had a frame-work in it, as represented in Fig. 38, the centre of gravity would obviously be at A, the centre of this frame-work. But if there were no frame-work, and perpendicular lines were supposed to be drawn from different points of suspension, C, B, D, and E, these would intersect at the point A, showing that this is the centre of gravity, according to the rule for finding it given in § 97. So, also, the centre of gravity of an empty box, or an empty ship, would be an imaginary point in the space inside. In a hoop it is the centre of the hoop's circle.

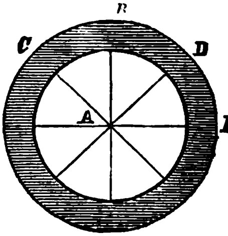


Fig. 38.

100. **The Centre of Gravity Seeks the Lowest Point.**—The centre of gravity always takes the lowest place which the support of the body will allow. In a suspended body, therefore, it is always directly under the point of suspension. To get to the one side or the other of this position it must rise. This the attraction of gravity forbids, and if by any force it is made to rise, this attraction at once brings it back. This is manifest in the case of a suspended ball, Fig. 39. If the ball be moved to *b*, it will, on being let go, re-

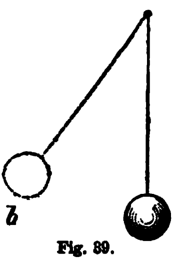


Fig. 39.

turn to its first position, simply because its centre of gravity, in obedience to the earth's attraction, seeks the lowest place possible. From inertia (§ 49) it moves beyond this point, and continues to vibrate back and forth for some time; but when its motion is stopped, it hangs perpendicularly; that is, in such a way that its centre of gravity shall have the lowest possible position. I add a few other illustrations of the same point. When a rocking-horse is at rest, its centre of gravity is directly over the point at which it touches the floor, for thus it has its lowest possible place. If it be rocked, the centre of gravity is moved to a higher point, and for this reason it rocks back again. The same is seen in the swing, the cradle, the rocking-chair, etc. Most interesting illustrations of the same thing are found in the Laggan, or Loggan Stones as they are called, several of which are seen on the rugged parts of the British coast. An immense rock, which has been loosened by some convulsion, rests with a slightly-rounded base on another rock which is flat, and it is so nicely balanced that one person alone can produce a perceptible rocking motion in it. I saw, many years ago, a large rock near Salem, Massachusetts, thus situated. There is one also in Great Barrington, Massachusetts.

101. **Farther Illustrations.**—It is because the centre of gravity always seeks the lowest place that an egg lies upon its side. When on its side, the centre of gravity is

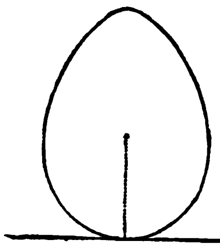


Fig. 40.

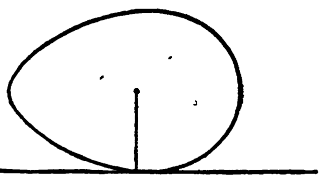


Fig. 41.

at its lowest point, as is manifest from comparing Fig. 40 with Fig. 41 (p. 71). Children often have a toy, called a witch, which illustrates the same thing in another way. It is a piece of light substance, as pith, with a shot fastened in one end. It always stands up on its loaded end, and can not be made to lie down on its side, because the centre of gravity would not then be at the lowest point. There is an amusing Chinese toy of the same kind. It is a figure of a fat old woman, Fig. 42, loaded with lead at the bottom, so that its centre of gravity is at *a*. If the figure be thrust over to one side, as shown by the dotted lines, the centre of gravity is raised, and the upright position is at once resumed. If the toy were not loaded, it would lie in the position represented in Fig. 43, just as the egg lies on its side.

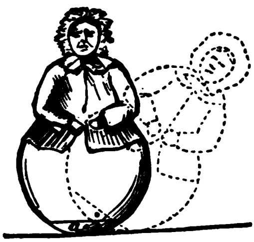


Fig. 42.

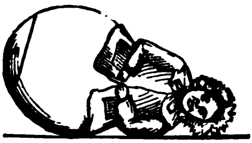


Fig. 43.

102. **Curious Experiments.**—You can not hang a pail of water on a stick laid upon a table, as represented in Fig. 44, for the centre of gravity is not supported. But if you place another stick as a brace, in the manner represented in Fig. 45 (p. 73), so as to push the pail under the table, it will hang securely, because the centre of gravity is now under the point of suspension. The explanation of the following experiment is the same: Run a large nee-

Fig. 44.

Fig. 45.

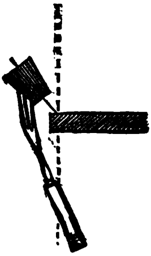


Fig. 46.

dle through a cork; fasten to the cork a fork, and you can suspend the whole on the edge of a table, as seen in Fig. 46. Here the centre of gravity is directly under the point of suspension, which is at the point of the needle. The same can be said of the very common toy represented in Fig. 47. The horse, made of very light material, stands securely, because the centre of gravity of the whole is in the heavy ball, which is under the point of suspension. If the horse be made to rock back and forth, the centre of gravity in the ball moves in a curved line, as in the case of a ball suspended by a string (Fig. 39). It is at its lowest place only when the horse is at rest. The hanging of a cane with a hook-shaped handle on the edge of a table is to be explained in the same way.

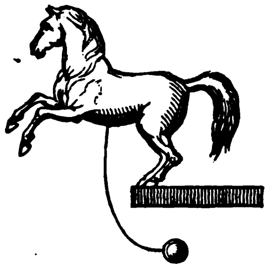


Fig. 47.

1●3. **Stability of Bodies.**—The firmness with which a body stands depends upon two circumstances—the height of its centre of gravity, and the extent of its base. The lower the centre of gravity, and the broader the base, the firmer does the body stand. A cube, rep-

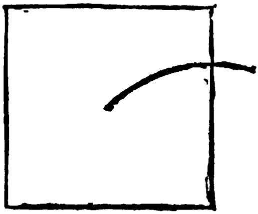


Fig. 48.

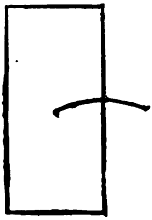


Fig. 49.

Fig. 50.

resented in Fig. 48, is more stable, that is, less easily turned over, than a body shaped as Fig. 49, because it has a larger base. The contrast is still greater between Figs. 48 and 50. The reason of the stability of a body with a broad base is found in the fact, that in turning it over the centre of gravity must be raised more than in turning over one of a narrower base. The curved lines indicate the paths of the centres of gravity as the bodies are turned over. In the case of a perfectly round ball, the base is a mere point, and therefore the least touch turns it over. Its centre of gravity does not rise at all, but moves in a horizontal line, as shown in Fig. 51. The pyramid is the firmest structure in the world, because it possesses in the highest degree the two elements—a broad base, and a low position of the centre of gravity. On both these accounts the centre of gravity must ascend considerably when the body is turned over, as seen in Fig. 52.

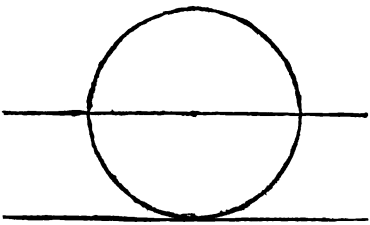


Fig. 51.

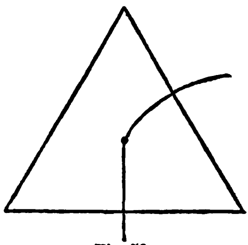


Fig. 52.

104. **Bodies not Upright Unstable.**—When a body does

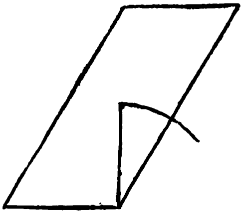


Fig. 53.

not stand upright, its stability is diminished simply because only a portion of the base is concerned in its support. In Fig. 53 the base is broad, but the body is so far from being upright that the centre of gravity bears upon the very extremity of the base on one side, as the perpendicular line from it indicates. The least jostle will turn it over, because the centre of gravity need not ascend the least when this is done. You see, then, that the less upright a body is, the less of the base is of service in its support, because the farther is the line of direction of the downward pressure of the centre of gravity from the centre of the base.

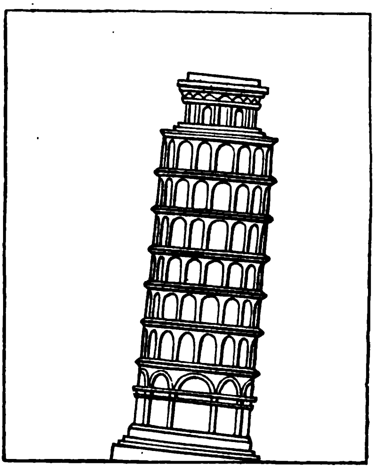


Fig. 54.

The famous tower of Pisa, Fig. 54, one hundred and thirty feet high, overhangs its base fifteen feet. It was undoubtedly built intentionally in this way to excite wonder and surprise, for what would otherwise have been a very unsafe structure is rendered stable and safe by the arrangement of its materials. Its lower portion is built of very dense rock, the middle of brick, and the upper of a very light porous stone. In this way the centre of gravity of the whole structure is made to have a very low position.

105. **Familiar Illustrations.**—You see now the expla-

nation of the fact which common experience teaches every one, that the taller is a body, and the narrower its base, the more easily is it overturned. This is exemplified in the two loads, Fig. 55. The base is the space included by the wheels. The centre of gravity is so high in the tall load that a perpendicular line drawn from it falls outside of the base if the cart come upon a considerable lateral inclination of the road. But the smaller load, under the same circumstances, is perfectly secure from overturning. A high carriage is more easily overturned than a low one, for the same reason: A stage, if loaded on its top, is very unsafe on a rough road. Stability is given to articles of furniture by making their bases broad and heavy, as you see in tables supported by a central pillar, candlesticks, lamps, etc. The tall chairs in which children sit at table would be very insecure if their legs were not widely separated at the bottom, thus widening the base of support. In the ladder, so commonly used now in picking fruit, a broad base is furnished between the foot of the ladder and the two standards which are spread out to sustain its top.

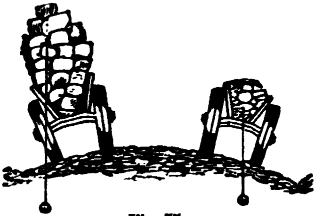


Fig. 55.

106. **Support of the Centre of Gravity in Animals.**—The base of support which quadrupeds have, viz., the space included between their four feet, is quite large; and this is one reason that they walk so soon after birth. A child does well that can walk at the end of ten or twelve months, for the supporting base is quite small compared with that of a quadruped. It consists of the feet and the space between them. It requires skill, therefore, in the child to manage the centre of gravity in standing and walking, and this is gradually acquired. If one should grow up without ever standing on his feet, he

would find, as the infant does, that some training is necessary to enable him to do it. It is on account of the smallness of the base furnished by the feet that the statue of a man is always made with a large base or pedestal. Although we exert considerable skill in walking, by no means so much is requisite as the Chinese ladies must put in exercise with their small feet. Still more skill is exercised by one who has two wooden legs, or one who walks on stilts. The base made by the feet can be varied much by their position. If the toes be turned out and the heels brought near to each other, the base will not be as large as when the feet are straight forward and far apart, as is manifest in Figs. 56 and 57. It is for this reason that the child, in his first essays at standing and walking, instinctively manages his feet as in Fig. 56.

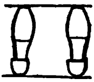


Fig. 56.

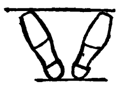


Fig. 57.

107. **Motions of the Centre of Gravity in Walking.**—In walking, the centre of gravity is alternately brought over one foot and the other, and so moves in a waving line. This is very manifest as you see people before you going down the aisle out of a church. When two are walking together, if they keep step the two waving lines of their centres of gravity run parallel, as in Fig. 58, and they


Fig. 58.

walk easily; but if they do not keep step these lines run as in Fig. 59, and the movement is both awkward and

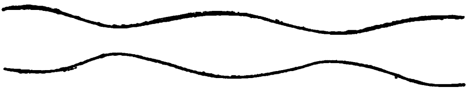


Fig. 59.

embarrassing. The line of movement of the centre of gravity is always slightly waving *upward* also, as seen in Fig. 60 (p. 78). In the case of a man with wooden

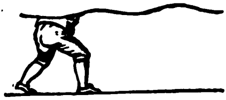


Fig. 60.

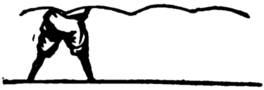


Fig. 61.

legs the line would not be gently waving, but somewhat angular, as represented in Fig. 61.


Fig. 62.


Fig. 63.

108. **The Centre of Gravity and Attitudes.**—The object of various attitudes assumed under different circumstances is to keep the centre of gravity over the base of support. A man with a load on his back would not assume the position of Fig. 63, but that of Fig. 62, so that the centre of gravity of his load may be directly over his feet. So a man carrying any thing in front leans backward, as in Fig. 64. In ascending a hill a man appears to lean forward, and in descending to lean backward; but in fact he is in both cases upright in reference to the plain on which the hill stands, as may be seen in Fig. 65. A perpendicular line drawn from his centre of gravity strikes the ground midway between the feet, that is, in the middle of the base, and if prolonged would go straight to the centre of the earth. When one rises from a chair he draws his feet backward, and then bends his body forward to bring the centre of gravity


Fig. 64.

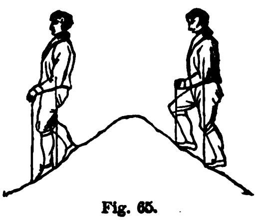


Fig. 65.

over the feet. Unless this is done, it is impossible to rise, at least deliberately, as you will find by trying the experiment. A man standing with his heels close to a wall can not stoop forward and pick up any thing, for the wall prevents him from moving any part of his body backward, and therefore when he stoops forward, the centre of gravity being brought far in advance of the base, he loses his balance and falls. A man who did not understand this undertook to stoop in this way to pick up a purse containing twenty guineas, which he was to have if he succeeded, the forfeiture in case of failure being ten guineas. Of course his centre of gravity made made him lose his wager.

109. **Rope-Dancers, Tops, etc.**—Great skill is exhibited by the rope-dancer in supporting the centre of gravity. Similar skill is seen in feats of balancing, as, for example, in balancing a long stick upright on the finger. In these cases the centre of gravity is very little of the time directly over the point of support. It is kept in constant motion nearly but not quite over this point, this unstable equilibrium, as it is called, being vastly less difficult to maintain than stable equilibrium; that is, keeping the balance in one unvarying position. It is the motion of the top that makes it to stand upright upon its point—a very beautiful example of unstable equilibrium. The centre of gravity revolves around a perpendicular line, at exceedingly little distance from it at first, but greater and greater as its motion becomes less rapid, till at length the centre of gravity gets so far from this line that the top falls. For a similar reason an intoxicated man may not be able to keep himself up if he undertake to stand still, and yet may do so if he keep moving. As in the case of the top, his centre of gravity must be kept in motion, or he must fall.

CHAPTER VII.

HYDROSTATICS.

110. **What Hydrostatics Teaches.**—Hydrostatics is that branch of Natural Philosophy which treats of the pressure and equilibrium of liquids. The phenomena which it brings to view all result *from the influence of the attraction of the earth upon liquids.* It is for this reason that this subject calls naturally for our consideration after examining the general subject of attraction, as we have done in the previous chapters. In order to understand fully the phenomena of Hydrostatics, you must continually bear in mind the two grand characteristics of liquids. One is, that the particles move freely among each other (§ 9). The other is, that a liquid is almost entirely incompressible (§ 36).

111. **Level Surface of Liquids.**—It is the influence of gravitation upon liquids that gives them a level surface whenever they are not agitated by any cause. Observe how this is. A still body of water you may consider as being made up of layers of particles. Each layer will have all its particles equally attracted by the earth, and must therefore be level. If any of the particles were less attracted than their neighbors they would rise, as is the case when heat is applied, as you will see hereafter. Whenever the upper layers of the particles are disturbed by wind or any other cause, as soon as the disturbance ceases the particles will again take their places in level layers under the influence of gravitation.

112. **A Comparison.**—The particles of water may be compared to shot. If you have shot in a vessel, and they are heaped up in any portion of the surface, on shaking the vessel those that are highest will roll down, and the

result will be a level surface. They would do this without agitation if they were as smooth as the particles of water are. If we could have a microscope strong enough to distinguish the shape of the particles of water, the surface would probably appear like the level surface of shot in a vessel. But the particles of water are so exceedingly minute that the surface of water, when entirely free from agitation, is so smooth as to constitute a perfect mirror, often feasting our eyes with another world of beauty as we look down into its quiet depths. Water was man's first mirror, and one of the most beautiful passages in the "Paradise Lost" is the description of Eve's first waking after her creation at the side of a lake, and seeing her form reflected in its smooth waters.

113. **Surface of Liquids not Truly Level.**—Strictly speaking, the surface of a liquid is not level, but rounding. But it is so little so that it can not be perceived unless we take into view a very large surface, as the ocean. Here it is very manifest, for whenever a ship comes into port the first thing seen from the shore is the topmost sail, the rest of the ship being concealed by the water rounded up between it and the observer. This is illustrated in Fig. 66. At *a* the ship is just in sight,

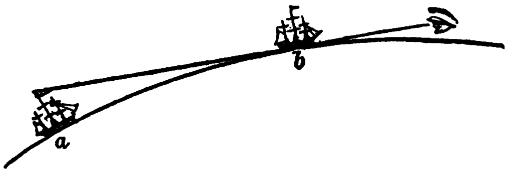


Fig. 66.

while at *b* it is so near shore that the eye sees the whole of it. If the earth had no elevations of land, or if there was water enough to cover them, the water would make a perfectly globular covering for the earth, being held to it by the force of attraction. The reason for this is precisely the same as was given in § 58 for the disposition

of a drop of liquid to take the globular form. As in that case, so in this, it can be demonstrated that each particle is attracted toward a common centre, and that this will produce in the freely-moving particles a uniformly rounded surface. What could thus be shown to be true if the earth were wholly covered with water, is true of the portions of water which now fill up the depressions in the earth's crust; and it can be perceived, as shown in the first part of this paragraph, in the case of any extended portion of it.

114. **Spirit-Level.**—What we call a perfectly level surface is, then, one all parts of which are equally distant from the centre of the earth, and is therefore really a spherical surface. But the sphere is so large that any very small portion of it may be considered for all practical purposes a perfect plane. A hoop surrounding the earth would bend eight inches in every mile. In cutting a canal, therefore, there is a variation in this proportion from a straight level line. As the variation is but an inch in an eighth of a mile, it is of no account in taking the level for buildings. Levels are ascertained by what is called a spirit-level. This consists of a closed glass tube, Fig. 67, nearly filled with alcohol. The space not occupied by alcohol is occupied by air. The tube is placed in a wooden box for convenience and security, there being an opening in the box at *a*. Now when the box with its glass tube is perfectly level, the bubble of air will be seen in the middle at *a*; but if one end be higher than the other, the bubble will be at or toward that end.

Fig. 67.

115. **Rivers.**—If a trough be exactly level, the water will be of the same depth at one end as at the other, for the surface of the water at both ends will be at the same distance from the centre of the earth. But raise up one end, and it is now deepest at the other end. If it were not so, the surface at the two ends would not be at the

same distance from the centre of the earth. Now if, with the trough thus placed, water run in at the upper end and out at the lower, you have exemplified what is taking place in all rivers—the water is in constant motion from the influence of gravitation, causing it to seek to be on a level. A very slight slope will give the running motion to water, for the particles are so movable among each other that in obedience to gravity they flow down the inclined plane to seek a level. Three inches declivity in every mile in a smooth straight channel will make a river run at the rate of about three miles an hour. The Ganges, which receives its waters from the Himalaya Mountains, in running 1800 miles falls 800 feet. The Magdalena, in South America, falls only 500 feet in running 1000 miles between two ridges of the Andes.

116. **How some Rivers have been Made.**—Changes are constantly produced in the earth by the disposition of water to seek a level. In doing this the water carries solid substances of various kinds from elevated places into depressed ones, tending to fill up the latter. New channels are also sometimes made by the water. The boy who makes a little pond with his mud-dam, and lets the water overflow from it into another pond on a lower level, as he sees a channel worked by the water between the two ponds becoming larger and larger, witnesses a fair representation on a small scale of some extensive changes which have in ages past taken place in some parts of the earth. It is supposed, and with good reason, that many rivers had their origin in the way above indicated. For example, where the Danube runs its long course there was once a chain of lakes. These becoming connected together by their overflow, the channels cut between them by the water continually became larger, until at length there was one long, deep, and broad channel, the river, while the lakes became dry, and constituted the fertile valley through which that noble river runs to empty into the Black Sea. It is said that a sim-

ilar process is manifestly going on in the Lake of Geneva, the outlet of it becoming continually broader, while the washing from the neighboring hills and mountains is filling up the lake. Towns that a century ago lay directly upon the borders of the lake have gardens and fields now between them and the shore; and Dr. Arnot says, "If the town of Geneva last long enough, its inhabitants will have to speak of the river in the neighboring valley, instead of the picturesque lake which now fills it."

117. **Canals.**—The management of the locks of a canal is in conformity with the disposition of water to seek a level. A ground view of a lock and a part of two adjacent locks is given in Fig. 68. The lock, C, has two pair

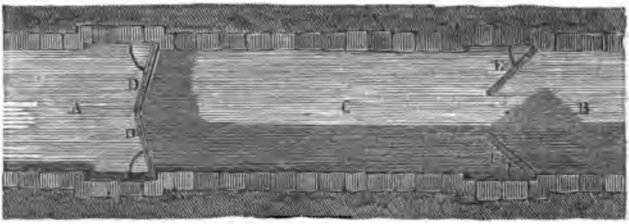


Fig. 68.

of flood-gates, D D and E E. The water in A is higher than in C, but the level is the same in C and B, because the gates, E E, are open. Suppose now that there is a boat in the lock B that you wish to get into the lock A. It must be floated into the lock C, and the gates E E must be closed. The water may now be made to flow from the higher level, A, into C, till the level is the same in both A and C. But this can not be done by opening the gates D D, for the pressure of such a height of water in the lock A would make it difficult, perhaps impossible, to do this; and besides, if it could be done, the rapid rush of water into C would flood the boat lying there. The discharge is therefore effected by openings in the lower part of the gates D D. These openings are covered by sliding shutters, which are raised by racks and

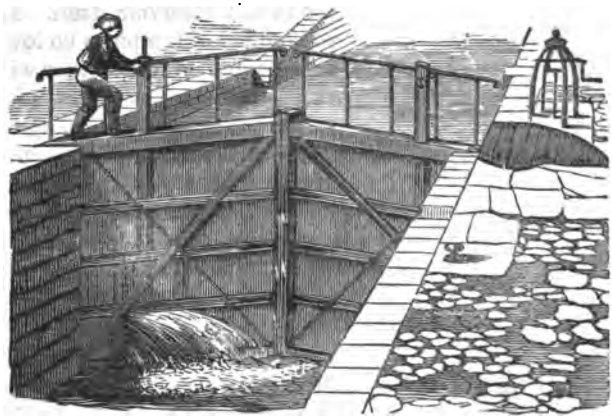


Fig. 69.

pinions, as represented in Fig. 69. When the water has become of the same level in A and C, the gates D D can be easily opened, and the boat may be floated from C into A. If a boat is to pass downward in the locks, the process described must be reversed.

Canals are also extensively used for supplying water by side openings to turn water-wheels for the working of machinery. The water turns the wheel by the force which gravitation gives it as it descends from the level of the canal to the level of the river.

118. **Other Illustrations.**—We see the tendency of fluids to be on the same level in other ways. In a coffee-pot the liquid has the same level in the spout as in the vessel itself, whatever may be its position, as seen in Fig. 70 (p. 86). If it be turned up so far that the level of the fluid in the vessel is higher than the outlet of the spout, the fluid runs out. If two reservoirs of water be connected together the water will stand at the same height in both, whatever the distance between them may be. So, also, in the aqueduct pipes that extend from a reservoir, the water will rise as high as the surface of the wa-

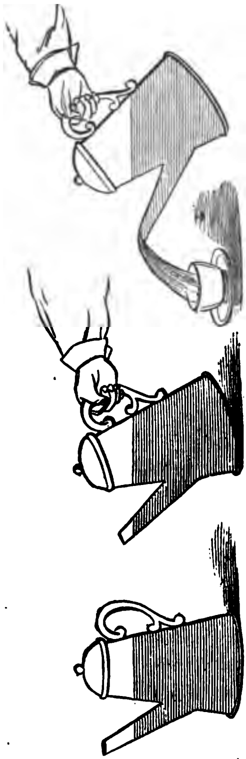


Fig. 70.

ter in the reservoir itself. If the outlets of the pipes be lower than this level the water will run from them, as in the case of the coffee. The cause of these and similar facts is the same as that of the level surface in vessels and reservoirs—the action of gravitation. This may be made plain by Fig. 71. Let the figure represent a vessel with divisions of different degrees of thickness, these divisions, however, not extending to the bottom of the vessel. Water in this would stand at the same level in the different apartments, just as it would if the vessel had no such divisions, as represented. This is simply because the attraction of the earth acts upon the water in the same way with the divisions as without them. And you can see that it will make no difference whether these divisions be thick or thin, or whether the apartments be near, as you see here, or far apart, as they are when branch pipes extend from a reservoir. A branch pipe may be considered as having the same relation to the reservoir as one of the narrow apartments in the figure has to the rest of the vessel. The

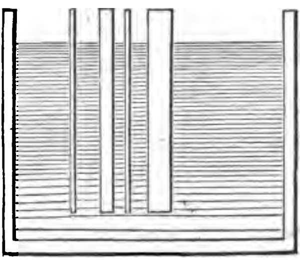


Fig. 71.

result is not at all affected by either the size or form of the tubes that may be connected with a common reservoir—a fluid will stand at the same height in all. Thus we have, in Fig. 72, tubes of various size and shape, *a b c d e*, connected with a reservoir, *r*, and if water be poured into one of them it will rise to the same height in all, just as in the different apartments of the vessel represented in Fig. 71. A man once thought that he had gained the great desideratum, perpetual motion, by a vessel constructed as in Fig. 73. He reasoned in this way: If the vessel contain a pound of water, and the tube only an ounce, as an ounce can not balance a pound, the water in the vessel must be constantly forcing that in the tube upward. It therefore must constantly run out of the outlet of the tube, and as it flows into the vessel the circulation must go on, and the only hindrance to its being a perpetual circulation would be the evaporation of the water. He was confounded when he found, on pouring water into the vessel, that it stood at precisely the same level in the vessel and the tube.

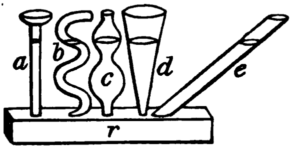


Fig. 72.


Fig. 73.

119. **Aqueducts.**—The ancients built aqueducts of stone at immense expense, in some cases spanning valleys at great heights, to supply their cities with water. At the present day the same object is effected at comparatively small expense with iron pipes laid under ground. No matter how much lower than the reservoir a valley crossed by the pipes may be, the water flowing through them will rise any where in their branches to the same height as it stands in the reservoir. It is supposed by some that the ancients were not aware of this fact; but by others that they were aware of it, and built their im-

mense aqueducts because they had no material for constructing large pipes.

120. **Springs and Artesian Wells.**—The principles which I have developed in the previous paragraphs will explain the phenomena of springs, common wells, and Artesian wells. The crust of the earth is largely made up of layers of different materials, as clay, sand, gravel, chalk, etc. When these were formed they were undoubtedly horizontal, but they have been thrown up by convulsions of nature in such a way that they present every variety of arrangement. As some of these layers are much more pervious to water than others, the rain which falls and sinks into the ground often makes its way through one layer lying between two others which are impervious to water, and so may make its appearance at a great distance from the place of its entrance, and at a very different height. How this explains the phenomena of springs, common wells, and Artesian wells may be made clear by Fig. 74. A A and B B B are designed to represent porous layers of earth lying between other layers which are impervious to water.

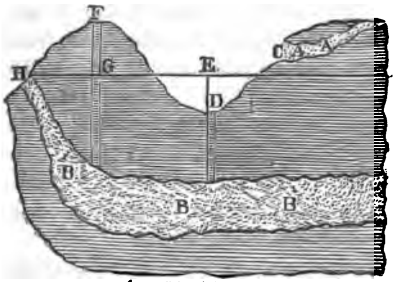


Fig. 74.

The water in A A will flow out at C, making what is commonly called a spring. If we dig a well at F, going down to the porous layer, B B B, the water will rise to G, because this is on a level with the surface of the ground, H, where the supply of water enters. From this point it may be raised by a pump. If the well be dug at D, the water will rise not only to the surface but to E, because this is on a level with H. Water is sometimes obtained under such circumstances from very great depths. In this case

the porous stratum containing the water is reached by boring, and then we have what is termed an Artesian well. The name comes from Artois, in France, where this operation was first executed. There is a celebrated well of this sort in Paris over 1800 feet deep, and the water rises 112 feet above the surface. More than 600 gallons are discharged every minute. "London," says Dr. Arnot, "stands in a hollow, of which the first or innermost layer is a basin of clay, placed over chalk, and on boring through the clay (sometimes of 300 feet in thickness) the water issues, and in many places rises considerably above the surface of the ground, showing that there is a higher source or level somewhere—probably among the Surry hills or those north of London."

121. **Pressure of Liquids in Proportion to Depth.**—The pressure of a fluid is in exact proportion to its depth. For, as the particles are all under the influence of gravity, the upper layer of them must be supported by the second, and these two layers together by the third, and every layer must bear the weight of all the layers above it. The increase of pressure at great depths produces the most striking effects. Thus if an empty corked bottle be let down very deep at sea, either the cork will be driven in or the bottle will be crushed in. A gentleman tried the following experiment: He made a pine-wood cork, so shaped that it projected over the mouth all around. He then covered this with pitch, and fastened over the whole several pieces of tarpaulin. The bottle, thus prepared, he let down to a great depth by attaching to it a weight. On raising it up he found that it contained about half a pint of water strongly impregnated with pitch, showing that the pressure of the water forced water through the several pieces of tarpaulin, the pitch, and the pores of the wooden cork. When a ship founders near land, the pieces of the wreck, as it breaks up, float to the shore; but when the accident happens in deep water, the great pressure forces water into the

pores of the wood, and thus makes it so heavy that no part of the vessel will ever rise again. When a man dives very deep he suffers much from the pressure on his chest. If we watch a bubble of air rising in water it is small at first, but it grows larger as it approaches the surface, because it sustains less pressure than when it was deep in the water. The force with which a fluid is discharged from an opening in a vessel depends on the height of the fluid above the opening. The difference in this respect between a full barrel and one nearly empty is very obvious. Most fishes, probably, can not bear the pressure of great depths, and so are commonly found on the coast, or on banks, as they are called, in the midst of the ocean.

122. **Sluice-Gates, Dams, etc.**—The application of the above principles in the construction of sluice-gates, dams, etc., is a matter of great practical importance. Let us look at this. As pressure in a fluid is always in proportion to the height of the fluid above the point of pressure, the pressure upon any portion of the side of a vessel containing a fluid must be in proportion to its distance from the surface; or, in other words, it is the weight of a column of water extending from this portion to the surface. Let A B C D (Fig. 75) represent a *section* of a cubical vessel, that is, one in which each side is of the same size with the bottom. The pressure on the point *a*, in the line A B, is that of a column of particles, A *a*. But A *a* is equal to *c b*, and *c b* is equal to *b a*. Therefore *b a* may represent the pressure on *a*. In the same way it can be shown that *e d* represents the pressure on *d*, *n m* the pressure on *m*, C B that on B. Therefore the pressure on all the points in A B will be

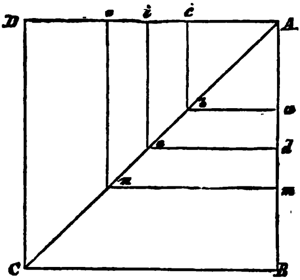


Fig. 75.

represented by lines filling up all the triangular space A B C, and this is half of A B C D, which represents the pressure on the line C B. It is clear, then, that as the pressure on a vertical line in the side is half that on a line at right angles to it in the bottom, the pressure on the whole side is half that on the whole bottom.

We see from the above demonstration why it is that a dam is built in the form represented in Fig. 76. We see, also, why in the monstrous vats in some of the English breweries (some of them holding many thousand barrels) the hoops and other securities at the lower part of them require to be made of very great strength. It is manifest, also, that if a sluice-gate is to be kept shut by a single support, this must be applied at one third of the distance from the bottom, there being as much pressure, as seen by Fig. 75, on the lower third as on the upper two thirds of the gate.

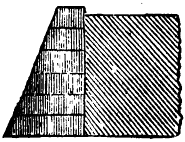


Fig. 76.

123. **Lateral Pressure in Fluids.**—The pressure of a liquid on the side of a vessel, of which I have spoken above, is a *lateral* pressure, and it is caused by the downward pressure of gravitation in the liquid. But how? The particles of a fluid are freely movable among each other, and therefore are ready to escape from pressure in any direction. The particles at *a*, Fig. 75, pressed upon by the column of particles extending above them to the surface, are ready to escape laterally, and would do so if there were an opening made in the vessel at that point. But if the vessel contained a block of ice, fitting it as accurately as the body of water, there would be no escape at the opening, because the particles of the solid are so held together that the downward pressure of the earth's attraction occasions no lateral pressure.

The manner in which the downward pressure of the earth's attraction causes lateral pressure may be made clear by Figs. 77 and 78. We will suppose that the par-

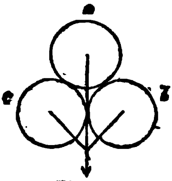


Fig. 77.

ticles of solids and liquids are alike round, and that a solid differs from a liquid only in having its particles firmly united by attraction. Let *a*, *b*, and *c*, in Fig. 77, represent three particles of a solid. As they are united firmly they will have a united pressure from the centre of gravity directly toward the centre of the earth, as represented by the arrow. Let now *d*, *e*, and *f*, Fig. 78, represent three particles of water. These being but very slightly coherent, will make each an independent pressure toward the earth's centre, as indicated by the arrows. It is plain that *d* tends to separate *e* and *f*, and will do so if they are left free to move in a lateral direction. For example, if *e* be at the side of a vessel, and an opening be made there, the downward pressure of *d* will give *e* a lateral movement, forcing it out of the opening.

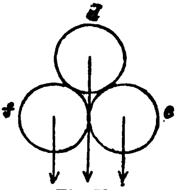


Fig. 78.

124. **Another View.**—To return to Fig. 75, observe that the lateral pressure at any point in the side of a vessel, as *a*, is occasioned *wholly* by the downward pressure of a vertical column of particles extending from that point to the surface. The neighboring columns of particles have nothing to do with it. The same thing is true in regard to any other point either in the line A B or another line drawn on the side of the vessel. It is therefore true of the whole side, that the pressure upon it is occasioned alone by the columns of particles that are in close proximity to the side, and not at all by the other columns of particles in the vessel. The number of these columns, therefore, in the vessel, or, in other words, the breadth of the body of water in it, makes no difference with the pressure on its side. For this reason two floodgates so little apart that a few hogsheads or even pails of water fill up the space between them, are as much

pressed upon as they would be if a lake or an ocean of water lay between them. It has been objected to the project of digging a ship canal between the Red Sea and the Mediterranean, that as the water in the former is twenty feet higher than in the latter, it would burst through the flood-gates with such force as to produce most disastrous results. But according to the principle which I have illustrated, there would be no more danger of this than there would be if two ponds were united by a canal, in one of which the water is twenty feet higher than in the other.

125. **Pressure in Liquids Equal in all Directions.**—We are now prepared to go a step farther. The pressure occasioned by gravitation in fluids operates equally in all directions when the fluid is at rest. That is, any particle of a liquid is pressed equally in all directions. If it were not so it would not remain at rest, but would be moved in the direction in which the superior pressure operates. Suppose that *a*, Fig. 79, is a stratum of particles in a vessel containing water at rest. The upward pressure on it being equal to the downward pressure, the stratum neither rises nor falls. If a body of liquid be disturbed by wind or any other cause, those particles which are raised above the common level in waves are pressed downward more than upward or laterally in obedience to the action of gravitation. They therefore move downward, pushing laterally and upward the neighboring particles, till the liquid regains its level surface and its state of rest. So, also, if any particles become heated they are lighter than their neighboring particles, and the latter being more strongly attracted than the former, push them upward in order to take their places. When all the liquid comes to have the same temperature it is at rest, each particle having an equal pressure upon it in all directions.

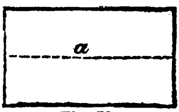


Fig. 79.

126. **Illustrations.**—If a bladder filled with water be

compressed by the hand, the water is pressed no more immediately under the hand than in any other part of the bladder, and wherever an opening be made the water will rush out with equal readiness. A hose-pipe as readily bursts upward as in any other direction. A large cork, if sunk in very deep water, will be uniformly reduced in its dimensions, showing that it has been pressed equally on all sides. In the experiments with the closed bottles (§ 121), the result is the same if the bottle be so sunk as to have its mouth downward. If two tubes, shaped as in Fig. 80, be thrust down into water, the water will rise with equal facility in both, although in the straight one the pressure which carries up the water is wholly upward, while in the bent one it is at the first downward.

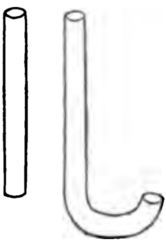


Fig. 80.

127. **Upward Pressure as the Depth.**—It has been shown that the downward and the lateral pressures are as the depth. The same is true of the upward pressure, for it is produced by the same cause—the attraction of the earth. Let us look at this. Why is any particle of a fluid pressed upward at all? It is from the struggle on the part of the neighboring particles to get below it. And why this struggle? It is from the attraction of gravitation, and so the greater this attraction the greater is the upward as well as the downward pressure. The upward pressure therefore differs at different depths as the downward pressure does. Thus, in Fig. 81, the upward pressure against the layer or stratum of particles, *b*, is greater than that against *a*, for the same reason that the downward pressure on *b* is greater than that on *a*. But the two pressures at *b* are equal, and so are they at *a*, and therefore each stratum remains at rest.

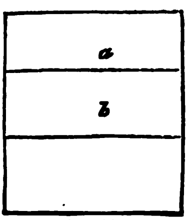


Fig. 81.

128. **Experiments.**—Some very neat experiments can be tried, showing that the upward pressure varies with the depth. Take a large glass tube, A B C D, Fig. 82, and let there be fitted to one end a circular plate of brass, which may be held there by a string, F. Thus arranged, plunge it quite deep into water, and you will find that you will not need to hold on to the string, for the brass disk will be held tight to the tube by the upward pressure of the water. Now draw up the tube slowly, and at length the disk will fall from the end of the tube. Why? Because the end of the tube has come to a point where the upward pressure of the water is less than the downward pressure of the disk. To have this experiment succeed, the end of the tube where the disk is applied must be very even and smooth. Another experiment may be tried in this way. Tie to one end of a glass tube a piece of thin India-rubber or bladder, and fill the tube partly with water. The India-rubber will of course bulge out or be convex from the weight of the water. Press the closed end down a little way in a vessel of water, so that the level in the tube shall be above the level in the vessel. The India-rubber is still somewhat convex, because, as the upward pressure upon it is in proportion to its distance from the surface of the water outside of the tube, it is not as great as the pressure downward of the higher water in the tube. Push the tube now so far down that the level in the tube is the same with that in the vessel. The India-rubber is now flat, because the downward and upward pressures upon it are equal, just as would be the case with a stratum of water in place of it. But press the tube lower down, and the India-rubber bulges upward into the tube, because the upward pressure is now greater than the downward.

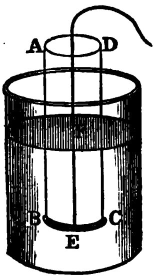


Fig. 82.

129. **Great Effects from Small Quantities of a Fluid.**—

You are now prepared to understand the explanation of some very striking phenomena in the pressure of liquids. If you take a perfectly tight cask, and, filling it with water, screw into its top a long tube, by pouring water into the tube you can burst the cask. To understand this you must bear in mind two facts—that the fluid in the cask is not compressible, and that its particles move freely among each other. Any pressure, therefore, exerted upon it is felt through the whole of it equally. "If the tube," says Dr. Arnot, "have an area of a fortieth of an inch, and contain when filled half a pound of water, this produces a pressure of half a pound upon every fortieth of an inch all over the interior of the cask; which is more than a common cask can bear." Suppose a small reservoir of water exists in the side of a mountain wholly closed up, and that water from a height above finds its way to it by a crevice, it may by its pressure even burst open the side of the mountain. And it matters not how large or small the crevice may be, for pressure in a liquid is only as the height. If the reservoir be ten yards square and an inch deep, and the fissure leading to it be but an inch in diameter and two hundred feet in height, it is calculated that the pressure of the water in the fissure would be equal in force to the weight of 5000 tons.

130. **Explanation.**—The manner in which these effects are produced may be made clear by Fig. 83. Let A be a close vessel filled with water, and let a tube, *b*, be made fast in it, with a movable plug or piston at *c*. If the surface of the water be pressed upon by this piston with the

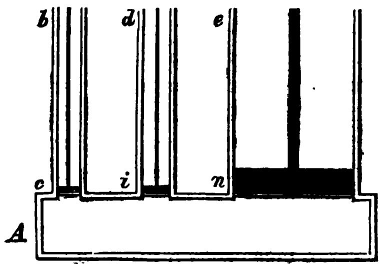


Fig. 83.

force of a pound, as the water is incompressible and its

particles are freely movable among each other, the pressure will be extended equally through all the water, and every portion of the vessel of equal extent with the tube's opening at *c* will be pressed upon with the force of a pound. If another tube, *d*, of the same size were inserted with a piston, *i*, the force of a pound applied to the piston *c* would push upward the piston *i* with the same force. And if there were several pistons of the same size, by pushing upon one with the force of a pound they would all be pressed upward with exactly this force. Farther, if *e* be a tube five times as large as *b*, its piston, *n*, will be forced upward with a pressure of five pounds by the downward pressure of a pound upon *c*. Suppose now that a pound of water were substituted for the piston *c*, the other pistons would be pressed upward as before. And if all the pistons be removed, the pound of water in *b* will press the water up the tube *d* with the force of a pound, and up the tube *e* with the force of five pounds.

To make this still more clear I will present it in a little different form. Let B, Fig. 84, be a close vessel with two tubes, one of which is five times as large as the other. If sufficient water be poured into the vessel to occupy a part of the tubes, it will stand at the same height in both tubes, as indicated. If there be a pound of water, then, in the tube *c*, there will be five pounds in *a*. Now if the five pounds of water in *a* made any more pressure on the whole body of water in B than the pound of water in *c* does, it would

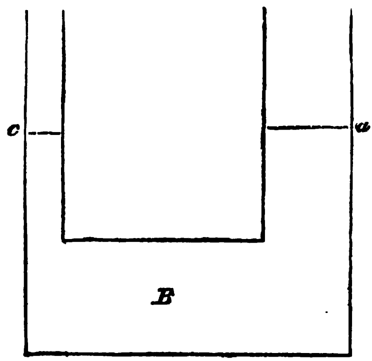


Fig. 84.

press up the water in *c* to a greater height. But this is impossible, as has been shown in § 118. Observe that the five pounds of pressure in *a* is spread over five times the area or extent of surface that the pound's pressure in *c* is. If the tube *c* have an area of an inch square, the water in it will exert a pressure of a pound on every square inch in the vessel. The water in *a* exerts a pressure of five pounds; but it must be remembered that it does not press with this force on every square inch, but on every space of five square inches, and that therefore its pressure on every inch is the same as that in the tube *c*.

131. **Hydrostatic Paradox.**—You see in the phenomena and explanations given above that a small quantity of a fluid can, under certain circumstances, exert an enormous pressure. This fact has been called the Hydrostatic Paradox. It does seem, at first view, incredible or paradoxical, when one asserts that a few ounces of water can be made to raise weights of hundreds or even thousands of pounds. But the explanations which I have given show you that there is no unexplainable mystery in the fact. The cause of it is the same as that which gives a level surface to liquids; viz., the force of gravitation acting upon a substance whose particles are freely movable among each other.

132. **Hydrostatic Bellows.**—The instrument called the Hydrostatic Bellows is represented in Fig. 85. It consists of two circular boards, A and B, united together by strong leather, and having a tube, C, through which water can be poured into it. The amount of weight which can be sustained on the bellows without forcing the water out of the tube depends on the size of the bellows. If the area of the tube is only one thousandth of that of the top of the bellows, a pound of water in the tube will balance a

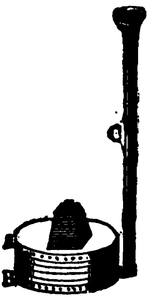


Fig. 85.

thousand pounds' weight on the bellows. It is for the same reason that in Fig. 84 one pound of water in the tube *c* balances five pounds in *a*. As the weight presses upon the top as a whole, it is the same as if there was a vessel of the same size with the bellows resting upon it and containing a thousand pounds of water. The water, in that case, would stand at the same height in the vessel and the tube. This shows that the Hydrostatic Paradox is only one of the exemplifications of the great fact that a fluid, from the influence of gravitation, seeks to be on a level. It is the water in the bellows seeking to be on a level with that in the tube that causes the upward pressure sustaining the weight.

When the weight on the bellows is less than is required to balance the water in the tube, the weight can be raised continually by pouring water into the tube. But observe that although the lifting force be so strong, it is very slow in its operation. If the comparative areas of the tube and the bellows be as above supposed, the water must fall in the tube ten inches in raising the weight the one hundredth part of an inch.

133. **Bramah's Hydrostatic Press.**—The principles which I have elucidated have been applied by Mr. Bramah in his Hydrostatic Press. This consists of a small metallic forcing-pump, Fig. 86, in which the water, *a*, is pumped up by the piston, *s*, worked by the lever, *c b d*, and forced into a strong and large cylinder, A. In this cylinder is a stout piston, S, having a flat

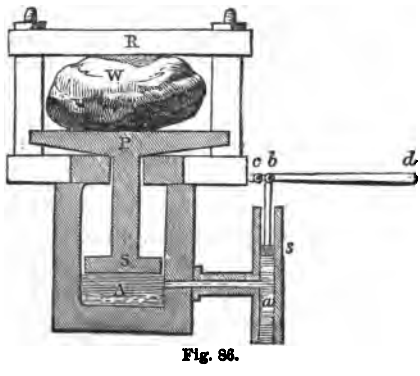


Fig. 86.

head, P, above. Between this plate and another, R, is placed the body, W, which is to be compressed. It is obvious that the pressure exerted will be in proportion to the difference between the size of the pump, *a*, and the cylinder, A, just as in the case of the bellows, it depended on the difference between the areas of the tube and of the top of the bellows. In the press the force of a pump is substituted for the pressure of a very high column of water, simply because it is more convenient. This press is of great service in the mechanic arts. It is used in pressing paper, cloth, hay, cotton, etc. It has also been recently used in raising enormous weights. The tubes of the celebrated bridge over the Straits of Menai were raised by a machine constructed on this principle.

CHAPTER VIII.

SPECIFIC GRAVITY.

134. **Nature of the Subject.**—We now come to a very interesting subject, which is at least intimately connected with Hydrostatics, if it may not be considered a part of it. The principles which have been developed in the chapter on Hydrostatics in relation to liquids are to be applied here to various kinds of substances. And as we proceed you will see that all the phenomena brought to view in this chapter are to be referred to the same cause with those of the previous chapter; viz., the attraction of gravitation.

135. **Specific Gravity Defined.**—Before proceeding with the investigation I will give you the definition of specific gravity. The specific gravity of any substance is its weight as compared with the same bulk or volume of other substances. Water is taken as a standard, and its specific gravity is for convenience called 1. Mercury,

then, is said to have a specific gravity of 13.5, for it is thirteen and a half times as heavy as the same volume of water. It is easy to see how the specific gravities of different fluids may be ascertained. One mode, and the most obvious one, is to weigh in a vessel equal quantities of them. In what way the specific gravities of solids are ascertained will be explained in another part of this chapter.

136. **Action of Gravity on Solids in a Liquid.**—The reason that a very heavy substance, as a stone, sinks in water is simply that the earth attracts it more strongly than it does the water, and so drags the stone down through it. If the stone lay upon a bladder filled with water, it would press upon it with the force with which it is attracted by the earth. But where water is not thus confined, the stone thrusts its particles to the one side and the other till it gets to the bottom.

It is the attraction of gravity, also, that makes light substances, as wood and cork, rise in water. In this case the water is attracted by the earth more strongly than the wood or cork, and so gets below it, and in so doing pushes the lighter substance up above itself.

But you will observe that the wood, on rising in the water, does not come completely out of it and lie upon the surface, but a part of it remains immersed in the water. The explanation of this will furnish you with the key to the understanding of many very interesting facts.

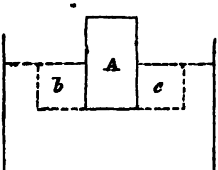


Fig. 87.

Suppose that half of a block of wood, A, Fig. 87, weighing a pound, is above the surface of water. As it is attracted to the earth with the force of a pound, it has pushed to the one side and the other just a pound of water, and taken its place. It is drawn down toward the earth with the same force with the pound of water on either side of it, *b* or *c*. If it were attracted any more than

with the force of a pound, that is, if it weighed more than a pound, it would displace more than a pound of water. If it were of just the same weight with the same volume of water, it would displace a volume of water equal to itself; it would be wholly immersed, and would stay any where in the water, wherever you placed it, because it is attracted by the earth with the same force that the same bulk of water is.

137. **Farther Explanation.**—Suppose water in a vessel divided into equal portions of a pound each, as represented in Fig. 88. Now suppose that the portion *a* should at once change into solid ice without at all altering its bulk or weight. It would not move from its position, because it is attracted by the earth precisely as much as when it was water, and as much as is each of the equal portions of water around it. But as water on becoming ice does really increase in bulk, and therefore become lighter, this block of ice would rise so that a part of it would be above the surface.

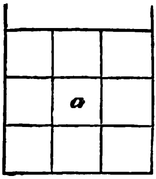


Fig. 88.

The lighter a substance is that is immersed in water, the more there will be of it above the surface. Take two blocks of wood of different weights though of the same size. Suppose the heaviest one, A, Fig. 89, is one third lighter than the same bulk of water. One third of it will be above the surface. If the other, B, is half the weight of water, half of it will be above the surface. We should say, then, that the specific gravity of the wood in the first block is two thirds of that of water, and the specific gravity of the wood in the second is one half that of water.

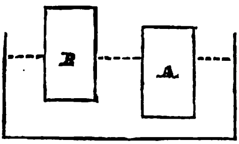


Fig. 89.

138. **Illustrations.**—There are many interesting facts that illustrate the principles which I have developed. A stone is lifted much more easily in water than in air, be-

cause of the support afforded by the upward pressure of the water. A boy will often wonder why he can lift a very heavy stone to the surface, but can get it no farther. When a bucket of water is drawn up a well much less exertion is required to raise it through the water than through the air after it emerges from the water. While it is in the water you raise only the bucket itself, the water in it having no weight, being sustained by the water around it. But when it comes to the air you have the weight of the water added to that of the bucket. When a person lies in a bath for some time, on raising his arm from the water it seems to be very heavy. The reason is, that it has had for so long a time the support of the water that when it is lifted into the air the want of this support is sensibly felt, just as we perceive the difference between raising a bucket of water through water and raising it through air. It is said that Archimedes took in the full idea of the principles of specific gravity as his limbs felt the liquid support of a bath, and so overjoyed was he with the discovery, that he ran home crying out all the way, "Ευρηκα! ευρηκα!"—I have found it! I have found it! It was a rational joy, for he had found a principle of immense value to science and to the world.

139. **Boats and Life-Boats.**—A boat of iron will float with as much of it out of water as one of wood of the same size, provided that the iron be made so thin that the boat is not heavier than the wooden one. For what is it that floats? Not the iron or wood, but a wooden or iron boat filled with air. If it were filled with water instead of air it would sink, the specific gravity of the materials of which it is built being on the whole of greater specific gravity than water. Life-boats have in their structure either a large quantity of cork or air-tight vessels of tin or copper, and in this way they are made so light that they will float even when filled with water.

As the weight of a body can be estimated from the quantity of water which it displaces, we can very readily

estimate the weight of the load of a canal-boat, as its form is so simple and regular. In order to do this we must first know how far the boat sinks in the water when empty, or, in other words, how much water it displaces.

140. **Specific Gravity of Animals.**—Birds have a much less specific gravity than animals that walk, in order that they may mount up easily in the air. Their light feathers increase greatly their bulk, as you may see whenever a bird is stripped of them. Besides this, the bones are hollow and communicate with the lungs. Birds that swim, as ducks, swans, etc., have so small a specific gravity—that is, are so large in proportion to their weight—that but a small part of the body is under water, and the motion of their feet is not required at all to sustain them, but only, like the action of oars, to propel them along. Insects are of small specific gravity, those that fly the most swiftly being the lightest. Fishes are very nearly of the same specific gravity with water, and hence require but little muscular effort to move about in their element. They are assisted much in rising and falling by a contrivance by which they can instantaneously alter their specific gravity. They have an air-bladder, which they can dilate or contract at pleasure. When dilated, the bulk of the fish is increased and his specific gravity lessened, and he rises easily and at once. By compressing it he as readily sinks.

141. **Specific Gravity of the Human Body.**—The human body, when the chest is filled with air, is so much lighter than water that it will float with about half the head above the surface. A knowledge of this fact, with proper presence of mind, might ordinarily save persons from drowning; for if the body be put in the proper position, the feet downward and the head thrown backward, the nose and mouth will be out of the water. So little is required in the way of support to keep the whole head out of water, that persons who can not swim are often saved from drowning by catching hold of very small pieces of

wood. An oar would support half a dozen men, if they would be satisfied with keeping only the head out of water; but if each one struggle to get his whole body upon the oar, they may all be lost.* A life-preserver is a great aid in preservation from drowning, for it dimin-

* I take the following from Dr. Arnot:

The reasons that so many people are drowned in ordinary cases, who might easily be saved, are the following:

1. Their believing that continued exertion is necessary to keep the body from sinking, and hence their generally assuming the position of a swimmer, in which the face is downward, and the whole head must be kept out of the water to allow of breathing. Now as a man can not retain this position without continued exertion, he is soon exhausted, even if a swimmer, and if not, the unskillful attempt will scarcely secure for him even a few respirations. The body raised for a moment by exertion above the natural level, sinks as far below when the exertion ceases; and the plunge, by appearing the commencement of a permanent sinking, terrifies the unpracticed individual, and renders him an easier victim to his fate.

2. From a fear that water entering by the ears may drown as if it entered by the nose or mouth, a wasteful exertion is made to prevent it; the truth being, however, that it can only fill the outer ear, or as far as the membrane of the drum, and is therefore of no consequence.

3. Persons unaccustomed to the water, and in danger of being drowned, generally attempt in their struggle to keep their hands above the surface, from feeling as if their hands were tied while held below; but this act is most hurtful, because any part of the body kept out of the water, in addition to the face, which must be so, requires an effort to support it which the individual is supposed at the time incompetent to afford.

4. Not having reflected that when a log of wood or a human body is floating upright, with only a small portion above the surface, in rough water, as at sea, every wave in passing must cover the head for a little time, but will again leave it projecting in the interval. The practiced swimmer chooses this interval for breathing.

5. Not knowing the importance of keeping the chest as full of air as possible; the doing which has nearly the same effect as tying a bladder of air to the neck, and without other effort will cause nearly the whole head to remain above the water. If the chest be once emptied, and if from the face being under water the person can not inhale again, the body is then specifically heavier than water, and will sink.

ishes the specific gravity of the body. It is commonly an air-tight bag fastened round the upper part of the body, which can be filled by blowing into it through a pipe which has a valve in it. "On the great rivers of China," says Dr. Arnot, "where thousands of people find it more convenient to live in covered boats upon the water than in houses on the shore, the younger male children have a hollow ball of some light material attached constantly to their necks, so that in their frequent falls overboard they are not in danger."

When a person is drowned the body sinks because in the struggle much of the air in the lungs is lost, just as the fish sinks when his air-bladder is contracted. It is, however, so little heavier than water after this is done, that it very readily rises when any gas is produced in it by putrefaction. It is a common popular notion that firing cannon over the water will raise the drowned. But it can produce no effect, unless perhaps the agitation caused by the concussion may hasten a very little the rising of a body which from commencing putrefaction is about to rise.

In wading a river the feet press upon the bottom with only a force equal to the weight of half the person's head, this being the difference between the weight of the body and the weight of the same bulk of water. Now this pressure is not sufficient to give a sure footing against even a moderate current. Many persons have been drowned from ignorance of this fact. A man carrying a load may often ford a river safely where without a load to press him down, and thus give him a sure footing, he would be carried down the stream. So a man may walk in deep water upon broken glass with impunity.

142. **How to Ascertain the Specific Gravity of Solids.** —It results from the upward pressure of water that a body weighs less in water than in air. Take a piece of gold or any other substance, *a*, Fig. 90 (p. 107), and weigh it suspended as you see from one of the scales.

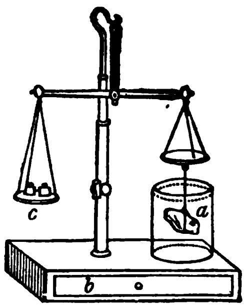


Fig. 90.

Introduce the gold now into a cup of water, and you will find that a part of the weight must be taken from the opposite scale to preserve the balance. The weight which you take from the scale will be the weight of a quantity of water equal in bulk to the piece of gold; for the immersed body is supported with a force equal to the weight of the water it displaces (§ 137). By comparing, therefore, its weight in water with its weight in air we determine its specific gravity. Thus if a lump of gold weigh nineteen ounces, and on being weighed in water weighs eighteen, it will prove that gold is nineteen times as heavy as water. And if a lump of copper weigh nine ounces in air and eight in water, it is nine times as heavy as water. Calling water, therefore, 1, the specific gravity of gold is 19, and of copper 9. It is obvious that a body of the same specific gravity with water would weigh nothing when immersed in water, for it would be supported with an upward pressure precisely equal to its own weight, just as the same bulk of water is. A pound of water, therefore, will weigh nothing in water. The experiment can easily be tried. Weigh a glass bottle, suspended on one arm of the scale-beam, and then put a pound of water in it. On immersing it in water it will be balanced if you take out the pound weight in the opposite scale.

143. **Archimedes and the Crown.**—Hiero, King of Syracuse, stipulated for a crown of pure gold. But suspecting the maker of it of adulterating the gold, he called upon Archimedes to detect the imposture. He did it in this way: He procured two lumps of gold and silver of the same weight with the crown, and observed the quantity of water which each displaced. He then tried the crown, and found that it displaced less than the silver

and more than the gold, and therefore concluded that it was an alloy of the two metals. All this was suggested to him by his experience in the bath, referred to in § 138.

144. How to Ascertain the Specific Gravity of Liquids.—There are several modes of ascertaining the specific gravities of different liquids. The instrument called a Hydrometer furnishes the most common mode. This is used chiefly in determining the quality of spirit. The more alcohol and the less water spirit contains the less is its specific gravity. The Hydrometer consists of two bulbs of glass, A B, Fig. 91, with a slender stem, C, which is graduated. In the lower bulb are a few shot or a little mercury, to give the instrument its proper weight, and to make its centre of gravity to be in the lower part. The lighter the fluid to be tested is the lower will the instrument sink in it. This is a very accurate instrument, detecting the slightest adulteration in spirits. Dr. Arnot tells an amusing story of the detection of a Chinese trader in liquors. He had sold a quantity of liquor to the purser of a ship, averring it to be of the same quality with a sample which he had given him. The purser tried it with his Hydrometer, and found it to be of greater specific gravity than the sample. The Chinese promptly denied the fraud; but on being told the exact quantity of water which he had added, he was so much confounded that he immediately confessed his guilt, and made ample amends. When the Hydrometer was shown to him he offered a large price for what appeared to him to be a magical instrument, foreseeing that it would be of great advantage to him in his business.

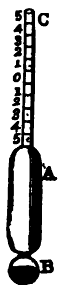


Fig. 91.

In Switzerland and in the north of Italy, where the peasants bring their milk to a common dairy, and are allowed a quantity of cheese at the end of the season in proportion to the amount of milk which they have brought, a Hydrometer is used to test the quality of the

milk. There is a propriety in this, not only as a safeguard against adulteration, but because there is a difference of quality in the milk of different cows, some giving a much more watery milk than others.

145. **Centre of Gravity in Floating Bodies.**—The same principles which apply to the centre of gravity in bodies standing on a firm basis apply also to floating bodies. That the centre of gravity may be low in a loaded vessel the heavy part of the cargo is put underneath, and generally ballast of stone or iron is necessary for the same purpose. In large flat-boats, the base of support being extensive, there is not the same need of taking care that the centre of gravity be low. If a ship be laden in part with an article which will dissolve in water, there is much danger, if the ship should leak, that this portion of the cargo shall be dissolved and be pumped out with the bilge-water, thus altering the trim of the vessel, or removing the centre of gravity from over the middle line, and bringing it too far forward, or carrying it too far back, making the ship wholly unmanageable. Four large English ships, in part loaded with saltpetre, were supposed to be lost from this cause in 1809 off the Isle of France. The immense ice-islands, or icebergs, which float about in summer in the polar regions, by melting irregularly often change the place of their centre of gravity, and in turning over present one of the most sublime spectacles in nature. A mountain of ice, extending high in the air and deep in the sea, suddenly turns over, and produces a rolling of the ocean which is often felt at the distance of many leagues.

CHAPTER IX.

PNEUMATICS.

146. **What Pneumatics Teaches.**—As Hydrostatics treats of the pressure and equilibrium of liquids, Pneumatics treats of the same in air and the gases, or aeriform substances. The name comes from the Greek word *πνευμα*, meaning air, breath, spirit.

147. **Air Material and has Weight.**—That air is a material substance has been already proved to you, for it was shown in § 46 that it has impenetrability, one of the essential properties of matter. It has extension also, for bodies of air can be obtained in various shapes confined in vessels, so that we can speak of cubes and spheres of air; and besides, the ultimate atoms (§ 15) of air must have shape or extension. That air has weight can be proved by weighing it as you would any other substance. Let a hollow globe, A, Fig. 92, having a neck with a stop-cock, B, be emptied of air and weighed. If now you open the stop-cock, and so let in the air, the other beam of the scale will rise, because the globe is heavier than it was before. The additional weight required to make the scales balance will indicate the weight of the air which the globe contains. It is one eight hundredth ($\frac{1}{800}$) of the weight of the same volume of water. How the globe can be emptied of the air will be shown in another part of this chapter.

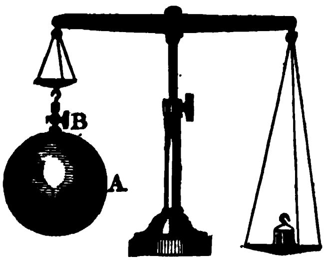


Fig. 92.

148. **Air Attracted by the Earth.**—The weight of the

air is simply the result of the attraction of the earth (§ 52). Air is attracted by the earth just as water is; and the water takes its place below air because it is attracted more strongly than the air. It is from the attraction of the earth that air descends into any hollow spot in the earth when water is removed from it. It takes the place of the removed water because from the influence of attraction it gets as near to the earth as possible. If you put into a vial mercury, water, and oil, the mercury will be at the bottom, because it is more strongly attracted by the earth than the other fluids. The water will be next, then the oil, and lastly, over all, there is air, that being less attracted than any of the other substances. It is this attraction of the air by the earth that gives us all the phenomena of Pneumatics.

149. **Why Some Things Fall and Others Rise in Air.**—Most substances fall in air for the same reason that very heavy substances sink in water. They fall because the earth attracts them more strongly than it does the air. The reason that some substances rise in air is precisely the same as that given in § 136 for the rising of substances in water. The air being attracted more strongly than they are pushes them up to get below them, as cork or wood is pushed up by water. Thus a balloon filled with hydrogen gas rises in air for the same reason that a bladder filled with air rises in water. So, also, smoke rises in air, just as oil rises in water.

150. **Thickness of the Earth's Air-Covering.**—The air makes a covering for the earth about fifty miles deep. If the earth were represented by a globe a foot in diameter, the air might be represented by a covering a tenth of an inch in thickness. The line *a*, Fig. 93, gives us the

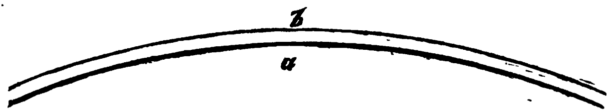


Fig. 93.

curve of the surface of such a globe, and the space between *a* and *b* represents the comparative thickness of the covering of air. This is ascertained by calculation from the pressure of the air upon the earth. It is just as the depth of water may be calculated from the pressure which it makes. We do not take this mode of ascertaining the depth of water, because we can measure it from the surface by sounding. But we should be obliged to adopt it if we lived at the bottom of water, as we do at the bottom of the sea of air.

151. **How the Air-Covering Adheres to the Earth.**—The earth flies on in its yearly journey around the sun at the rate of 1100 miles per minute, and yet it holds on to this loose airy robe by its attractive force, so that not an atom of it escapes into the surrounding ether. Of itself it is disposed to escape; and it would do so, and be diffused through space, if the attraction of the earth for it were suspended. For, unlike liquids, the air has no disposition to keep together; that is, there is no attraction between its particles. On the other hand, there is a repulsion, so that they are disposed to keep far apart, and are kept together only by pressure. It is the pressure of the earth's attraction that keeps them together to the extent of fifty miles all around it.

152. **Compressibility of Air.**—In looking at the influence of gravitation upon air, it must be remembered that air is very compressible, while water is very nearly incompressible. While, therefore, in a body of water the particles are very little nearer together at the bottom than at the surface, the particles of the air are much nearer together close to the earth than they are far away from it. For as all the particles of the air are attracted or drawn toward the earth, those below are pressed together by the weight of those above. The air is therefore thinner as we go up from the surface of the earth, and in the outer regions of the sea of air it is too thin to support life. Even at the tops of very high mountains,

or the heights sometimes reached by balloons, disagreeable effects are often experienced from the thinness of the air. The air has been compared, in regard to its varying density at different heights, to a heap of loose compressible substance; as, for example, cotton-wool, which is quite light at the top, but is pressed more and more together as you go toward the bottom. Hydrogen gas has only one fifteenth the weight of air at the surface of the earth; and therefore the hydrogen balloon rises till it reaches a height where the air is so thin that the balloon is of the same weight with an equal bulk of air, and there it stops.

153. **In what Aeriform Substances and Liquids are Alike.**—You have seen in § 36 and § 38 how the air and gases differ from liquids. But in one very important respect they are alike, viz., the movability of their particles. Hence pressure is in air, as well as in water, equal in all directions, so that in the experiment with the bladder, in § 126, it makes no difference in the result whether there be water or air in it. For the same reason pressure is as the depth in aeriform substances as in liquids, and the laws of specific gravity apply to the one as well as to the other.

You are now prepared to understand the results of *the action of gravitation upon air and the gases;* or, in other words, the principal phenomenon of Pneumatics.

154. **Pressure of the Atmosphere.**—The amount of the pressure of the atmosphere is very readily estimated, the mode of doing which I will speak of in another part of this chapter. It presses with a weight of fifteen pounds on every square inch. Suppose that you extend your outspread hand horizontally in the air. You feel no pressure upon it, but there is a pressure of some two or three hundred pounds of air upon it. If your hand be five inches long and three broad it presents a surface of fifteen square inches, on every one of which the atmosphere is pressing with the weight of fifteen pounds.

That is, there is a pressure on the upper surface of your hand of a column of air weighing 225 pounds. So, also, on the lid of a box only thirty inches square, there is a pressure of 13,500 pounds. The whole pressure on the body of a man of common size is about fifteen tons. But why is it that the lid of the box is not broken in, your hand not borne down, and your body not crushed? It is simply from the fact, shown in the previous chapter in regard to liquids, and in this in regard to aeriform substances, that the pressure is equal in all directions. The lid and the outspread hand are therefore balanced by an upward pressure equal to the downward, and the body has the pressure on all sides the same. If the air could be removed from within the box the lid would be crushed in; if from under the hand, that would be borne down; and if from one side of the body, the body would be forced violently in that direction till it met with an opposing pressure.

But besides this equal pressure of the air on all sides, there is air within the pores and interstices of all bodies that are not very dense, and its particles are subject to the same laws as are those on the outside.

All this can be made clear to you by the air-pump.

155. **Air-pump.**—In Fig. 94 you have a representation of an air-pump as commonly arranged. At *a a* are two pump-barrels, the pistons in which are worked by means of the handle, *b*. Those pumps are very nicely made, and the frame-work, *d e d e*, to which they are attached, is very

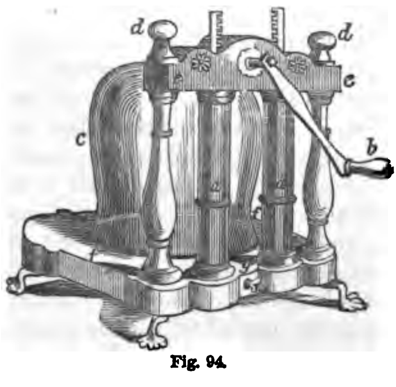


Fig. 94.

strong and firm, so that the pumps may work evenly. There is a large, smooth, metallic plate, *f*. At *c* is a bell-shaped glass vessel, close at the top, but open at the bottom, the edge of which is ground very true, so that it may fit exactly on the metallic plate. In the middle of the plate is an opening which leads to the pump-barrels, and it is through this that the air is pumped out of the glass receiver, *c*. If we wish to let the air in after we have pumped it out we loosen the screw at *g*, for from the opening here is a passage to the opening in the middle of the plate.

The operation of the air-pump can be made clear by the plan in Fig. 95. But one pump-barrel, *a*, is represented, with a piston, *c*, working in it. In the piston there is a valve, *i*, opening upward, and also one at *b*, in the beginning of the passage leading to the centre of the plate where is the receiver, *d*. The working of the instrument is thus: If the piston be forced down, the air under it, being compressed, will close the valve at *b*, and will rush upward through the valve *i* in the piston. Let the piston now be raised; the resistance of the air above it will close the valve *i*, while the valve *b* will be opened by the air rushing from the receiver, *d*, through the passage, *e*, to fill the space between the piston and *b*. You see, then, that every time that the piston is drawn up air passes out of the receiver through the valve *b* into the space between this valve and the piston. None of this air which has passed out can go back again, for the moment that you press upon it by forcing downward the piston the valve *b* is shut down, and the air escapes from the pressure by passing out through the valve *i*. Each time, therefore, that you

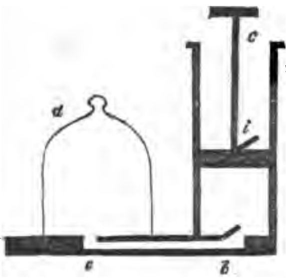


Fig. 95.

work the piston up and down you pump out some of the air from the receiver; and if you pump for some time there will be exceedingly little air left in it, and that will of course be diffused throughout the receiver. It will be thin, like that in the upper regions of the atmosphere.

156. **Experiments.**—When the receiver is full of air it can be moved about on the plate easily, and can be lifted from it. But work the pumps a few strokes and you will find that the receiver is firmly fastened to the plate, for the air within, being made thin, presses with little force compared with the air outside. If the pumps be worked for some time no force could release the receiver from the pressure without breaking it. But loosen the screw, *g*, and thus let the air in, and the equality of the pressure on the outside and inside is at once restored. Take off now this large receiver, and place a small glass jar, open at both ends, on the plate, with the hand covering the upper opening, as represented in Fig. 96. On exhausting the air the hand is so firmly pressed into the glass that it requires considerable force to disengage it from the pressure. If we tie a piece of bladder or India rubber over this jar, as in Fig. 97, and then pump out the air, the bladder at first is pressed in as represented, and if we pump on it at length bursts with a loud report. It would make no difference in the result of the experiment if the jar were shaped as in Fig. 98, for the pressure is the same in all directions. The resemblance between air and liquids in this respect may be illustrated thus: Suppose that a flat fish covers with

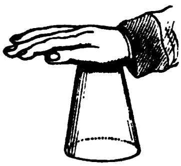


Fig. 96.

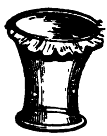


Fig. 97.

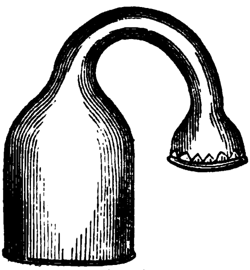


Fig. 98.

one of its sides the end of the tube of a pump. He feels no uncomfortable pressure, because the water in the pump and that below it press equally upon him. If, now, the pressure of the water in the pump could be suddenly taken off by the piston, the fish would be pressed upward into the tube, as the bladder is pressed upward in Fig. 98, or downward in Fig. 97, or as the hand is pressed downward in Fig. 96. The Magdeburg Hemispheres, Fig. 99, illustrate very impressively the pressure of the atmosphere. They consist of two hemispheres whose edges at A fit very accurately upon each other. The air is exhausted through the stem where you see the stop-cock, and then the handle B is screwed on. The force required to pull these hemispheres apart depends upon the extent of their surface. In the famous experiment at Magdeburg, in 1654, by Otto von Guericke, the inventor of the air-pump, two strong hemispheres of brass of a foot in diameter were employed, and it required the force of thirty horses to separate them. In Fig. 100 you see a receiver with an opening at the top. Cemented in this opening is a wooden cup, *a*, terminating in a cylindrical piece, *b*. If mercury be poured into the cup, on exhausting the air from the receiver the mercury will be forced through the pores of the wood by the external air, and will fall in a silver shower. A tall jar, *c*, is placed there to receive it, to prevent any of it from going down into the opening in the metallic plate.

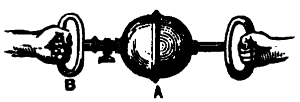


Fig. 99.

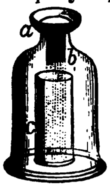


Fig. 100.

157. **The Sucker.**—The boy's sucker illustrates the pressure of the air. It is simply a circular piece of leather with a string fastened to its centre, as seen in Fig. 101. When the leather is moistened and pressed upon a smooth stone, on pulling the string a vacuum is made


Fig. 101.

between the middle of the leather and the stone, and the leather adheres by its edges to the stone, just as the receiver adheres to the plate of the air-pump when the air is pumped out. There are many animals that have contrivances of a similar character. The gecko and the cuttle-fish furnish interesting examples, as noticed in my Natural History, pages 198 and 320. Snails, limpets, etc., adhere to rocks by a like arrangement. Some fishes do the same. There is one fish called the remora, that attaches itself by suckers to the side of some large fish or a ship, and thus enjoys a fine ride through the water, without any exertion on his part. In all such cases it is water instead of air that makes the pressure, but the principle is the same. Flies and some other insects can walk up a smooth pane of glass, or along the ceiling overhead, because their feet have contrivances akin to the boy's sucker. The hind-feet of the walrus are constructed somewhat like the feet of the fly, enabling this huge animal to go up smooth walls of ice.

158. **Density of the Air Dependent upon Pressure.**—The fact that the degree of the density of the air is dependent on pressure has been already shown in § 152. The same thing can be shown in various ways with the air-pump. If a small bladder, partly filled with air, Fig. 102, and loaded with a weight so as to sink in water, be placed in a jar of water, and the whole be set under the receiver of the air-pump, on exhausting the air the bladder will swell out with the expanded air in it, and will rise as seen in the figure. The reason is, that the pressure being taken off the surface of the water, the bladder bears only the pressure of the water, and not that of the air with the water, and so the air in it expands and becomes less dense. If an India-rubber bag be partly filled with air, Fig. 103 (p. 119), and put under the receiver, on exhausting the air, the surrounding pressure being

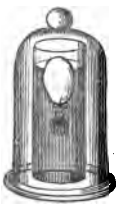


Fig. 102.


Fig. 103.

thus taken off from the bag, the air in it becomes expanded, that is, rarefied. For the same reason, if a vessel with soap-bubbles in it be placed under the receiver, on pumping out the air the bubbles will become much enlarged. A very pretty experiment illustrating the same thing may be tried in this way. Let an egg with a hole made in its small end be suspended in a receiver, as represented in Fig. 104, a wine-glass being beneath it. On exhausting the air the egg will all run out of the shell into the wine-glass, and then, on admitting the air, it will run back again into the shell. The explanation is this: There is air in the large end of the egg. As soon as the pressure of air is taken off from all about the egg the air in the egg expands, forcing out the contents; but when the air is admitted into the receiver the air in the egg is at once condensed into its former small bulk by the surrounding pressure.

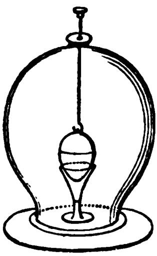


Fig. 104.

159. **Hydrostatic Balloon.**—The philosophical toy represented in Fig. 105 illustrates very beautifully the influence of pressure upon the density of the air. The balloon in the jar of water is of glass, with a small orifice at its lower part. Care must be taken in putting water in the balloon to have just enough to make it of a little less specific gravity than water. In that case it will be at the top of the jar, with a very little of its top above the surface of the water. Now tie a piece of India-rubber cloth over the top of the jar, and the apparatus is complete. On pressing upon the India rubber the balloon will go down in the jar, and on taking off the pressure it will rise. The explanation is this: The pressure upon the India rubber is felt through the


Fig. 105.

whole body of the water in the jar, and forces a little more water into the orifice of the balloon, condensing the air that is there. The balloon consequently becomes heavier, and has a greater specific gravity than water, and sinks in it. But when the pressure is taken off, the condensed air in the balloon, by its elasticity, returns to its former bulk, expelling the surplus water just introduced, and the balloon, becoming therefore as light as before, rises. Grotesque figures of glass may be managed in the same way. The Cartesian image, Fig. 106, is an example. This has air in its upper part, *a*, and water up to *c d*. When pressure is made on the India rubber more water is forced into the image through the tail, *b*, and it goes down like the balloon, to rise again when the pressure is taken off.

Fig. 106.

160. **Air in Substances.**—I have said that there is air in the pores and interstices of wood, flesh, and a great variety of substances. In all these cases the presence of the air can be made manifest by taking off the pressure of the surrounding air, and thus allowing the air in these substances to expand. If an egg be placed in a jar of water, Fig. 107, under the receiver of an air-pump, on exhaustion being made air-bubbles will constantly rise in the water from the egg. So, too, a glass of porter, Fig. 108, will have its surface covered with foam, the carbonic acid gas in it escaping freely when the pressure of the air upon it is taken off. The same thing may be seen to some extent even in water, for it always contains some air. For the same reason a shriveled apple, with the pressure of the air taken from it, will become plump and fair, but will shrink at once to its shriveled state when the air is admitted into the receiver.


Fig. 107.

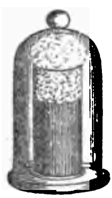


Fig. 108.

161. **Elasticity of the Air.**—All the phenomena cited in § 158, § 159, and § 160 exhibit the elasticity of the air. It is from this property that it is always disposed to expand. It will do so whenever pressure is taken from it, or when it can overcome pressure to which it is subjected. This property is most strikingly exhibited when the air is much condensed by pressure. And the greater the condensation the stronger is the expansive or elastic force.

162. **The Condenser.**—In Fig. 109 you have the plan of an instrument called the Condenser. In A B, a cylinder, moves the piston, P. Air is admitted to the cylinder at F, and into the receiver, V, at G. The valve at F prevents any air from escaping from the cylinder, and the valve at G prevents it from escaping from the receiver. The operation of the instrument is this: If the piston be pressed downward, the pressed air in the cylinder shuts the valve F and opens G, and so enters the receiver V. If now the piston be raised, air rushes in at F to fill the space in the cylinder. It can not come from V, because the valve G is shut by its pressure. By working the piston for some time you can get a body of air into V of very great density. You see that this instrument is the very opposite of the air-pump. In the receiver, V, you have condensed air, while in the receiver of the air-pump you have rarefied air. If you compare the two instruments you will see that the opposite results are owing to different arrangement of the valves.

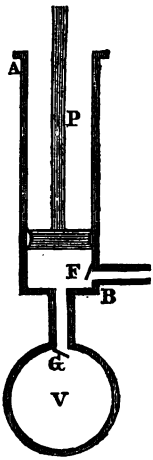


Fig. 109.

163. **The Gasometer.**—Gas is distributed in pipes from the gasometer at the gas factory by the agency of the elasticity occasioned by condensation under pressure. The apparatus, Fig. 110 (p. 122), consists of a large round vessel, G, open below, and sunk in a larger ves-

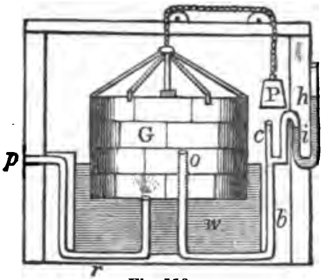


Fig. 110.

sel of water, *w*. We will suppose the vessel, G, to be full of water. Gas is introduced into it through the pipe, *p r*, the gasometer rising as it fills with the gas. P is a weight balancing the gasometer, and so permitting it to rise as the gas enters. The gasometer being filled, the gas is to be distributed. For this purpose weights are put upon the gasometer, so that the gas may be compressed. Under this pressure it by its elasticity seeks for more room, and obtains it by escaping through the pipe *o b c*. As the pressure on the gas needs to be regulated, there is sometimes a gauge, *h i*, attached, which shows the amount of the pressure. It is a bent tube with water in the bend. You see at once that the greater the pressure upon the gas the higher will the water be in the branch, *h*, of the gauge.

164. **Air-Guns and Pop-Guns.**—These illustrate the elasticity of condensed air. The air-gun is constructed in this way: A receiver, like V, Fig. 109, is made so that you can screw it on and off from the instrument. After being charged with condensed air it is screwed upon the gun, its stem communicating with the barrel. In order to discharge the gun there is a contrivance connected with the trigger for raising the valve, G, so that some of the condensed air may enter the barrel. On doing so, it by its sudden expansion rapidly forces out the contents. The principle on which the common pop-gun operates is the same. There is air confined between the two corks, *a* and *b*, Fig. 111 (p. 123). As the rod, R, is pushed quickly in, the cork *b* is carried nearer to *a*, so that the air between them is condensed. With the condensation the expansive force is increased; and when it becomes so great

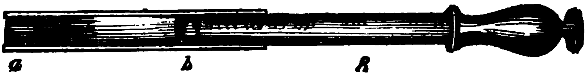


Fig. 111.

that the cork *a* can no longer resist it, it throws the cork out, and so quickly as to occasion the popping sound.

165. **Powder and Steam.**—The explosion of powder furnishes a good illustration of the expansive force of condensed air or gases. These gases are produced so suddenly from the powder that at the instant they are in a very condensed state, and therefore expand powerfully. So, also, steam has power in proportion to its condensation. When formed under the confinement of a boiler, on being allowed to escape it expands with great force. The application of the expansive power of steam will be treated of particularly in another part of this book.

166. **Retardation by Condensed Air in Gunnery.**—When a ball is fired it is constantly retarded in its flight by the resistance of the air, for it has to push the air away on every side in order to make its way through it. Of course, then, the more condensed the air is the greater is the resistance. Now it is condensed air that the ball is obliged to remove; for as it goes forward it, by its rapid pressure, condenses the air directly before it. And the more rapid is its flight the greater is the condensation, and therefore the greater the resistance. Besides, the retarding effect is increased by the tendency to a vacuum behind the ball. All this can be made clear by Fig. 112. Let B be a ball going very rapidly in the direction indicated by the arrow, the cloud representing the condensed air before it, and the space included in the two lines the vacuum behind it. It is obvious that the more rapidly the ball goes the less readily is the air pressed out of the way, and therefore the more it is condensed in front of the

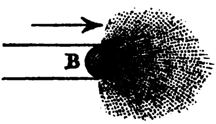


Fig. 112.

ball. At the same time the more rapid is the ball the less readily does the air close up behind it, and therefore the greater is the tendency to a vacuum there. For these reasons there is more retarding influence exerted by the air upon a ball in the first part of its course than in its latter part.

167. **Pressure of the Air on Liquids.**—If you plunge a tumbler into a vessel of water, and turning it over hold it so that its open part is just under the surface, it will remain full. The reason is that the weight of the air pressing upon the surface of the water in the vessel prevents the water in the tumbler from passing downward. Now if you introduce a bent tube under the tumbler, as in Fig. 113, and blow through it, the air that you force up into the tumbler presses the water down, taking its place. That is, the pressure of the air acts in opposition to the pressure of the air outside upon the surface of the water in the vessel. You take a jar, *a*, Fig. 114, and filling it with water, turn it over with its open end downward, the water will remain in the jar. You have here a representation of the pneumatic trough used by the chemist in collecting gases. To fill the jar *a* with gas he puts the mouth of the retort from which the gas issues under the jar *a*, and the gas passing upward expels the water, as the water is expelled by the breath from the tumbler in Fig. 113. In Fig. 115 (p. 125) is

Fig. 113.

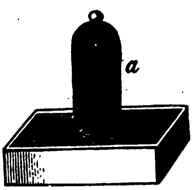


Fig. 114.

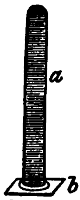


Fig. 115.

represented an experiment which shows not only that the pressure of the air sustains the column of water in the cases cited above, but also that it makes no difference in what direction this pressure is exerted. Take a large tube, *a*, closed at one end and open at the other, and fill it even full with water. Place, now, a piece of writing-paper over its mouth, and carefully invert the tube, as seen in the figure. The paper will remain, and the water will not run out. It is the pressure of the air that sustains the water, and the paper only serves to maintain the surface of the water unbroken. If the paper were not there the particles of the air would insinuate themselves among those of the water, and pass upward in the tube. You can try this experiment with a wine-glass, and may even succeed with a tumbler. We see in these experiments the reason that a liquid will not run from a barrel when it is tapped, if there be no vent-hole above, unless there be so large an opening made as to let the air work its way in bubbles among portions of the liquid. It is this entrance of the air that causes the gurgling sound in pouring a liquid from a bottle.

168. **Amount of Atmospheric Pressure.**—If, instead of the jar *a*, in Fig. 114, you have a tube thirty-four feet high, and closed at the top, situated as the jar *a* is, it will remain full of water. If the tube be longer the water will stand only at thirty-four feet, leaving a vacuum above it. It makes no difference what the size of the tube is; the result will be the same in all cases.* That is, a column of water thirty-four feet high can be sustained by the pressure of the atmosphere. It is easy, therefore, to estimate the weight or pressure of the air. The pressure of the column of water is found to be fifteen pounds to the square inch of its base, and this, of course, is the amount of pressure or weight of the atmosphere

* This is true except when the tube is so small that capillary attraction exerts considerable influence.

which it balances. Mercury is thirteen and a half times as heavy as water, and therefore the air will sustain a column of it only about thirty inches in height.

169. **Barometer.**—The weight of the atmosphere varies to some extent at different times, and the barometer is an instrument for measuring these variations. It is constructed on the principles developed in the previous paragraphs. In Fig. 116 is a representation of the instrument. A B is a glass tube about 34 or 35 inches long, closed at one end. It has been filled with mercury, and then inverted in a cup of the same liquid, C. The vacuum above the mercury is called the Torricellian vacuum, from Torricelli, an Italian, who first developed the principles of the instrument. The mercury generally, as stated in § 168, stands at about the height of thirty inches. But it varies from this with the weather. When the weather is bright and clear the air is heavier than this, and, pressing upon the mercury in the vessel, forces it up higher in the tube. But when a storm is coming the air is apt to be lighter, and therefore pressing less strongly on the mercury in the vessel, the mercury in the tube falls. The barometer is of great service, especially at sea, in affording the sailor warning of an approaching storm. An incident is related by Dr. Arnot which strikingly illustrates its value in this respect. He was at sea in a Southern latitude. As the sun set after a beautiful afternoon the captain foresaw danger, although the weather was perfectly calm, for the mercury in the barometer had suddenly fallen to a remarkable degree. He gave hurried orders to the wondering sailors to prepare the ship for a storm. Scarcely had the preparations been made when a tremendous hurricane burst upon the ship, tearing the furled sails to tatters, and disabling the masts and yards. If the ba-

Fig. 116.

rometer had not been observed the ship would have been wholly unprepared, and shipwreck, with the loss of all on board, would have been the result.

A water-barometer could be made, but it would be an unwieldy thing, for the tube must be over 34 feet long. Besides, it would not answer in very cold weather, as the water would freeze. So short a column of the heavy fluid, mercury, balances the weight of the atmosphere that a barometer made with this is of very convenient size; and then there is no danger of the mercury's freezing, except in the extreme cold of the Arctic regions.

170. **Barometer a Measurer of Heights.**—The atmosphere, as stated in § 152, diminishes regularly in density as we go upward. The rate of this diminution has been accurately ascertained, and therefore we can estimate heights by the amount of pressure on the mercury in the barometer. At a height of 500 feet the barometer will be half an inch lower than in the valley below. At the summit of Mont Blanc it stands but half as high as at its foot, indicating a height of 15,000 feet. Du Luc, in his famous balloon ascension from Paris, saw the barometer at one time standing at about twelve inches, showing an elevation of 21,000 feet.

171. **Relation of the Air's Pressure to the Boiling Point.**—Water heated to 212 degrees of Fahrenheit boils, that is, it becomes vapor. Now if water be heated on the summit of a high mountain it boils before it arrives at this degree of temperature. On the top of Mont Blanc it boils at 180 degrees, that is, 32 degrees below the boiling point of water at the foot of the mountain. This is because the pressure of the air acts in opposition to the change of water into vapor, and the less the pressure is the less heat will be required to vaporize the water. We may illustrate this influence of the pressure of air upon boiling by the following experiment. Let a cup of ether (which boils at 98 degrees) be placed under the receiver of an air-pump. On rarefying the air by the

pump the ether will boil. The general effect of pressure upon boiling may be prettily illustrated by another experiment. Boil some water in a thin flask over a spirit-lamp. Blow out the lamp, and, corking the flask tightly, let the boiling cease. If, now, you pour some cold water over the flask the boiling will commence again with considerable force. Why? Because you condense the steam which is over the water by the application of cold, and thus take off the pressure. Then, again, if, while the water is boiling, you pour hot water over the flask, the boiling ceases, because the heat favors the accumulation of steam, and therefore renews the pressure on the surface of the water.

You can see from what has been stated that most liquids have the liquid form because of the pressure of the atmosphere upon them. If there were no atmosphere, ether, alcohol, the volatile oils, and even water, would fly off in vapor; and the earth would be enveloped in a vaporous robe, for the particles of the vapors would be held to the earth by attraction, just as the particles of the air are now, § 151.

172. **Syphon.**—The pressure of air upon fluids is beautifully exemplified in the operation of the syphon. This instrument is simply a bent tube having one branch longer than the other. Its operation is shown in Fig. 117.

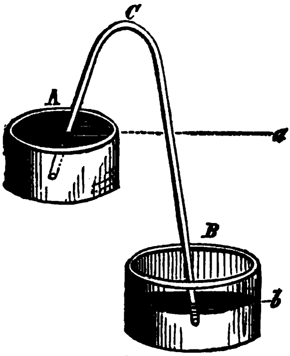


Fig. 117.

The tube having been first filled with the liquid, has its shorter branch in the liquid of the vessel A, which is to be emptied, and the other in the vessel B, which is to receive the liquid. As you see it here, the opening of the long branch is below the surface of the liquid in B. It

is manifest, therefore, that the air presses equally upon the surfaces in both vessels, tending to support the fluid in the tube, just as the fluid is supported in the jar in Fig. 114. But, notwithstanding these equal pressures, the liquid runs up the tube from A, and down its longer branch into B. Why is this? As the pressure of a column of fluid is as its height, there is greater pressure or weight in the longer branch than in the other; and it is this difference in weight that causes the flow from A into B through the syphon. The difference in the columns in the two branches is not the difference in length of these branches, but the distance between the levels of the fluid in A and B, that is, the distance from *a* to *b*. The operation, then, of the instrument is this. There is a constant tendency to a vacuum at C, the bend of the tube, from the influence of gravitation on the excess of fluid in the long branch over that in the short one. This tendency is constantly counteracted by the rise of fluid in the short branch, it being forced up by the pressure of the air upon the surface of the fluid in A.

If the syphon were so placed that the surface of the liquid in A is precisely on a level with that in B, as represented in Fig. 118, the liquid would remain at rest, for as pressure is as the height, § 121, and the pressures on the two surfaces are equal, there would be an exact balance. But let the surface in B be in the least lower than in A and the flow will begin. And the greater the distance between the two levels the more rapid will be the flow, for the greater will be the influence of gravitation in the long branch.

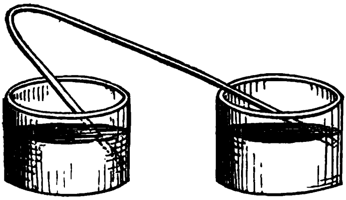


Fig. 118.

Again, if the end of the long branch of the syphon be free, as in Fig. 119 (p. 130), the syphon will operate in the same way, for the air, pressing in all directions equal-

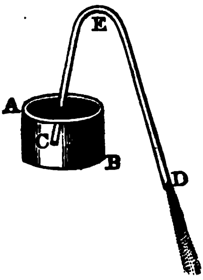


Fig. 119.

ly, tends to support the column of fluid in the long branch by a direct upward pressure, but is prevented from doing so by the excess of fluid in it above what is in the shorter one. The operation of the syphon is commonly represented in this way; but I have given first the arrangement in Fig. 117, in order that you might more clearly see the principle of the instrument.

173. **Uses of the Syphon.**—The syphon is used chiefly for discharging liquids from one barrel or vessel into another.

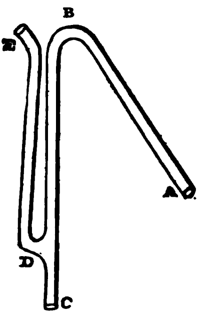


Fig. 120.

For convenience, it is often constructed after the plan of Fig. 120. To the long branch, B C, is attached the tube E D. It is used in this way: The end of the short branch, A, being introduced into the liquid to be drawn off, you place your finger upon C, and after filling the syphon by suction at E, you remove the finger and let the liquid run. The syphon has sometimes been used to drain pits and mines. It of course can never be used where the elevation over which the tube is to bend is over 34 feet from the surface of the water to be discharged, for then the air would not press the water up to the bend of the syphon.

174. **Cup of Tantalus.**—This cup, Fig. 121, has a syphon in it, the short branch, *b*, opening into the cup, and the long branch, *d*, having its outlet in the bottom. As you pour water into the cup it will remain there until you pour enough in to cover the bend of the syphon. As soon as this is done, the syphon being filled, the water suddenly flows out from the outlet, *a*, of the long branch.

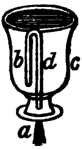


Fig. 121.

175. **Intermitting Springs.**—The operation of an intermitting spring is essentially the same with that of the cup of Tantalus. You have a representation of such a spring in Fig. 122. There is a cavity in a hill, supplied with water from a passage above. There is also a passage from it which takes a bend upward like a syphon. Now when the water in the cavity is low it will not run out from the syphon-like channel; but when the cavity becomes filled above the level of the bend the water will at once flow out, just as it does from the cup of Tantalus as soon as the bend of its syphon is covered.

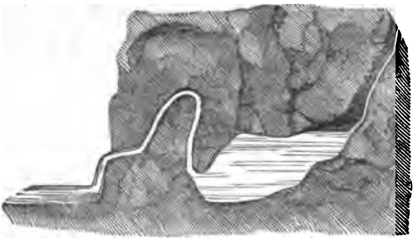


Fig. 122.

176. **Pumps.**—In Fig. 123 you have a plan of a common pump. A tube, C D, extends down into the well, W. Above this is the barrel of the pump, A B, in which the piston works up and down. There is a valve, F, in the piston, and another, E, at the bottom of the barrel. Both of them open upward. We will suppose that the pump is entirely empty of water. If, now, the piston descend, the valve E shuts down, and F opens, letting the pressed air between the piston and E pass upward. See what will happen when the piston rises. The air above the piston can not get below, for its pressure will shut the valve F. But there will be a tendency to a vacuum below the piston as it rises, and the air will go up through the valve E to fill

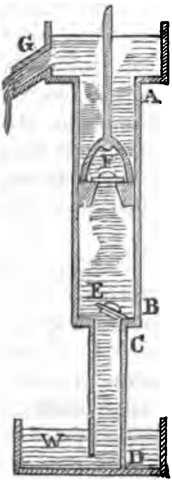


Fig. 123.

up the space. But why does the air rise? Because of the pressure of the air upon the surface of the water in the well. This forces up in the pump the water and the air above it, just in proportion as the downward pressure in the pump is lessened. If the pumping be continued all the air will soon be expelled, the water following it and flowing out at the opening, G. It is obvious that the pump will be useless if the valve E be over 34 feet above the surface of the water in the well, as the pressure of the atmosphere will not sustain a column of water higher than this.

177. **Suction.**—In common language, the operation of the pump is attributed to what is called a principle of suction, as if there was a drawing up of the water. But the water, you see, is not drawn, but forced, up. So it is with all operations of a similar character. In sucking up a fluid through a tube the fluid is forced up, because the pressure downward in the tube is removed. But how is it removed? It is done by a movement of the tongue downward from the roof of the mouth, thus causing a tendency to a vacuum, as the upward movement of the piston in the pump causes this tendency under it. To fill the space made by the movement of the tongue the air is forced up the tube, the liquid following; and, as in the case of the pump when the air is all expelled, the liquid will begin to discharge into the mouth.

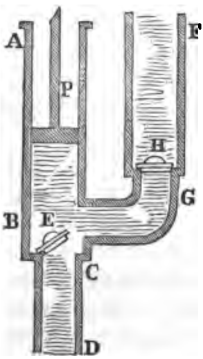


Fig. 124.

178. **Forcing-Pump.**—The forcing-pump is constructed differently from the common pump. Its plan is given in Fig. 124. It has a pipe, C D, and a barrel, A B, like the common pump. It has also the valve E at the bottom of the barrel. But it has no valve in the piston. Connected with the barrel is another pipe, F G, from which

the water issues. This has a valve, H, opening upward. The operation of the pump is obvious. As the piston is drawn up E opens and H shuts, and when it is forced down E shuts and H opens.

179. **Fire-Engine.**—The fire-engine has commonly two forcing-pumps, with a contrivance for making the water issue in a uniform stream. This contrivance can be explained in Fig. 125. The discharging pipe, L M, extends down into a large vessel, I K, which is filled with air. The uniformity of the stream depends upon the elastic force of compressed air, as you will see if I explain the operation of the machine. When the water is forced through the opening H, it rises to the level N O, compressing the air in I K, for the tube L M is too small to allow all the water to escape that comes from the larger tube, H E. Now the moment that the piston ceases to force the water through H, the elastic force of the compressed air operates, shutting down the valve H, and forcing the water up L M. The result, you see, is a continuous forcing up of the water through this tube, and therefore a uniform stream.

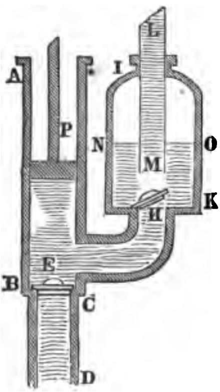


Fig. 125.

CHAPTER X.

MOTION.

180. **Universality of Motion.**—The world is full of motion. The rising and setting of the sun, the changes of the seasons, the falling of the rain, the running of rivers into the ocean, the ascent of water into the air by evap-

oration, the wind moving in silence or rushing on in its might, are familiar examples of motion constant and every where present. But with all this motion, sometimes in conflict and often variable, order and regularity reign. The causes of motion, though various in their operation, are kept by the Creator from producing confusion and disorganization by a few simple laws, which regulate the movements both of atoms and of worlds. The principal of these causes I will now briefly notice.

181. **Causes of Motion.**—Attraction is the most universal of the causes of motion in the universe. While it binds atom to atom, it also binds system to system throughout the immensity of space; and while it makes the stone fall to the ground, it moves the countless orbs forever onward in their courses. It is this which causes the tides to flow and the rivers to run down their slopes to the ocean, and thus by keeping up the never-ending motion of water all over the earth in seas, lakes, rivers, and the millions of little streamlets, diffuses life and beauty over the vegetable world, and gives to man the vast resources which we see developed in the numberless applications of water-power and navigation.

Heat pervades all matter, and is every where uniting its influence with the other causes of motion. It is heat that produces all the motions of the air, termed winds. It is heat that causes the rise of the water all over the earth in evaporation, so that it may be collected in clouds, again to descend to moisten the earth and keep the ever-flowing rivers full. Heat applied to water gives to man one of his best means of producing motion in machinery.

The agencies which Chemistry reveals to us are ever at work causing motion among the particles of matter; and though they generally work in silence, they sometimes show themselves in tremendous explosions, and in convulsions of nature.

Busy life is every where producing motion, more es-

pecially in the animal world. It gives to the myriads of animals, great and small, that swarm the earth not only the power of moving themselves, but also the power, to some extent, of moving the material world around them.

182. **Action and Reaction Equal.**—When any of the causes of motion act, the action is met by an opposite and equal reaction. If, for example, a blow be given, an equal blow is received in return. For this reason, if one in running hits his head against the head of another both are equally hurt. When a child knocks his head against a table, there is sound philosophy in the common saying that he has given the table as good a blow as he has received, though it may afford him no comfort. Many very interesting illustrations of this law of motion suggest themselves, of which I will give a few.

A swimmer, pressing the water downward and backward with his hands and feet, is carried along forward and upward by the reaction of the water. And in this case, as in every other, the greater the action the greater is the reaction; in other words, the more strongly he presses with his hands and feet, the more rapidly is he borne along by the reaction of the water against the pressure. A boat advances in proportion to the force with which the oars press against the water. So the rapidity of a steamboat depends on the force with which the paddles drive the water astern. Birds rise in the air by the reaction of the air against their wings as they are pressed downward. A sky-rocket pursues its rapid flight because a large quantity of gaseous matter issues from its lower end, and, being resisted by the reaction of the air, by its pressure throws the rocket upward. So if a ship fire guns from the stern its advance will be accelerated, but if from the bow it will be retarded. When a broadside is fired the ship inclines to the other side. In Fig. 126 (p. 136) is represented the plan of Barker's mill. It consists of a cylinder, *c*, arranged in a frame in such a way that it can revolve on the point upon which

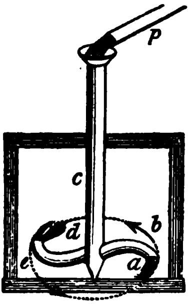


Fig. 126.

it rests. Water runs into it by a tube, *p*, and escapes by the branches, *a* and *d*. These are so arranged that the reaction upon the issuing water makes the cylinder revolve rapidly, causing the ends of the branches to whirl around as indicated by the dotted lines and arrows.

If a spring be compressed between two equal bodies, it will throw them off with equal velocities. If they are unequal, the velocity of the smaller body will be greater than that of the larger, and in proportion to its smallness. For this reason, when a ball issues from a cannon, though the cannon and the ball are equally acted upon by the elastic or expansive force of the gases set free by lighting the powder, the gun is moved but very little because the force is diffused through so large a mass, while the ball being so much smaller moves with great velocity. When a volcano throws stones from its crater the earth may be compared to the cannon, the stones to the ball, and the explosive materials throwing the stones to the exploding powder projecting the ball. As the cannon is moved as much as the ball, so is the earth moved as much as the stones, the only reason that it does not move as far and as rapidly as the stones being that the force is diffused through so large a bulk. These examples illustrate very well the relation of action and reaction, for whenever there is an action of one body upon another it is as if a spring were between the two bodies, acting equally upon both. When a man jumps from the ground it is as if a spring were compressed between him and the earth, and this expanding moves the earth exactly as much as it does the man. He really kicks the earth away from him. The motion of the earth is not obvious because it is diffused through so large a mass. The case is parallel to that of the ball

and cannon. The same force is exerted upon the man and the earth, but the man, like the ball, moves the most, and in proportion to his comparative smallness. So when a bird hops from the ground, the earth moves as really as the bird. If the bird hop from a twig, you perceive that the twig is moved by the pressing down of the bird as it rises. When it starts from the ground it exerts the same downward pressure, and moves the earth as really as in the other case it did the twig.

183. **Inertia Shown in the Communication of Motion.**—What is meant by the inertia of matter you have already learned in § 48. This property is exemplified in the communication of motion to any body, or, in other words, in setting it in motion. Of this I will give some illustrations. When the sails of a vessel are first spread to the wind the vessel does not move swiftly at once, for some time is required for the force applied to overcome the inertia of so large a mass, and to put it in rapid motion. Horses make a greater effort to start a load than they do to keep it in motion after it is started. If one be standing up in a carriage, and the horses start off suddenly, he falls backward, because his body, from its inertia, does not readily and at once partake of the motion of the carriage. If a person start forward quickly with a waiter filled with glasses in his hands, the glasses will slide backward. So if a person start quickly from his chair with a cup of tea in his hand, the tea will be thrown backward upon him.

You see from the foregoing illustrations that it requires some time to communicate motion to any body. I will give some illustrations of this fact of a more striking character. If a ball be thrown against an open door it will move the whole door, and perhaps shut it; but the same ball if fired will pass through the door without moving it perceptibly. In the latter case its velocity is so great that there is not time enough to communicate motion to the whole door, and it moves only that part

of it with which it comes in contact. A bullet thrown with but little force against a window will crack a whole pane of glass; but if shot from a pistol it merely makes a round hole. So, also, a cannon-ball having a great velocity may pass through the side of a ship, doing perhaps comparatively little damage, while one moving with much less velocity may do vastly more damage by splintering the wood to a considerable extent. For the same reason a rapid ball hitting a person may occasion less suffering and do less harm than a slow ball; for a rapid ball kills merely the parts which it touches, leaving the flesh around in a sound state, while the slow ball bruises over a large space. If a large pitcher filled with some heavy liquid be quickly taken up the handle will break, leaving the pitcher behind. Large dishes are often broken in this way when heavily loaded.

184. **Inertia Shown in the Disposition of Motion to Continue.**—Of this I will cite some illustrations. As in the case of the ship, in the first illustration in § 183, it takes time to communicate motion to the whole ship, or, in other words, to overcome its inertia, so when the ship is once in rapid motion it does not stop suddenly when the sails are taken down, but its inertia tending to keep it moving is gradually overcome by the resistance of the water. If one be standing up in a carriage in motion, and the horses suddenly stop, he will be thrown forward, for his body has a motion in common with the carriage, and from inertia is disposed to go on when the carriage stops. When you strike your foot against any thing to get the snow off, you give the foot and the snow a common motion together, then arresting the motion of the foot, the snow from inertia passes on. The same thing is illustrated in striking a book against any thing to get the dust off. If a ship strike upon a rock every thing on board which is loose is dashed forward. The earth as it revolves on its axis has a velocity at the equator of about 1000 miles an hour. If this revolution should be sudden-

ly arrested every thing loose on its surface, having acquired the motion of the earth, would be at once thrown eastward, just as the furniture, etc., on board ship are dashed forward when it is stopped by running against a rock. All the houses, and monuments, and structures of every kind would fall prostrate eastward. All the cities on our Atlantic coast would be plunged into the ocean; and while the waters would leave the western shores of the Atlantic, they would overflow its eastern shores, and deluge the continent of Europe, as water in a vessel on board a ship that had struck an obstacle would be thrown forward over its side.

185. **An Equestrian Feat.**—In the feat represented in Fig. 127 the only exertion made by the rider is to raise himself sufficiently to pass over the cord, and he comes down again upon the horse's back, simply because of the motion which he has in common with the horse, his feet going in the path represented by the dotted line. If he should attempt to throw himself forward, as in leaping from the ground, he would go too far, and perhaps strike upon the horse's neck instead of his back. Skill in jumping from a moving carriage consists in making proper allowance for the forward motion which is had in common with the carriage. Most persons are apt to overdo the matter, and so come to the ground prostrate, and with more violence than is necessary.

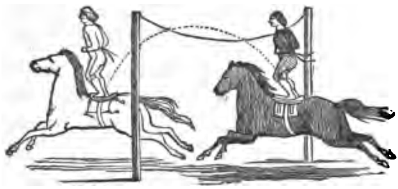


Fig. 127.

186. **A Case in Court.**—A dashing young man driving a light phaeton ran against a heavy carriage. His father was induced by his son's representations to prosecute the driver of the carriage for driving too fast. A knowledge of motal inertia very readily decided the case. The

son and his servant both declared that the shock of the carriage was so great against the phaeton that they were thrown over the horses' heads. They thus proved themselves guilty of the fast driving, for it was their own rapid motion that threw them out when the phaeton was stopped by running against the carriage. The following case is a parallel one. If two boats, the one of large size sailing slowly up stream, the other a small one sailing rapidly down, run against each other, a man standing in the bow of the one going down will be thrown much farther forward than one standing in the bow of the other.

187. **Course of Bodies Thrown into the Air.**—It results from the principle that I have illustrated that when any body, as a stone, is thrown, as we say, straight upward, it does not, in reality, go up or come down perpendicularly. If it did it would come down at a great distance from us. Suppose it takes two seconds for it to go up and to reach the ground. If we are at the equator, in that two seconds we move from the point where we threw up the stone nearly 3000 feet eastward, and therefore if the stone rose and fell perpendicularly it would fall 3000 feet westward of us. Why, instead of this, does it fall at our feet? Because that when thrown into the air it has not only the upward motion given by the hand, but also the forward motion of the earth. It is a case similar to that of the rider in Fig. 127, the horse representing the surface of the earth and the rider the stone. For the same reason a man on board of a steamboat, though it move fifteen miles an hour, tosses up his ball or orange and catches it as well as if he were on land. This he could not do if both he and his orange did not have the same forward motion that the boat does. So, also, if a man fall from a mast-head he reaches the deck at the foot of the mast when the vessel is sailing rapidly, just as he would if it were lying still at the wharf. If he did not by inertia retain the forward motion which he had

in common with the vessel he would fall at some distance behind the mast.

188. **The Earth and the Atmosphere.**—The air being held to the earth by attraction, § 151, it has a motion in common with the earth. It revolves with the earth just as the tire of a wheel revolves with the wheel. This being so, our winds are nothing but slight variations of this constant rapid whirl of the aerial coating of the earth. If the atmosphere were suddenly to stop whirling round with the earth we should move through it with a velocity of 1500 feet a second; and the destructive effect upon us would be the same as it would were the earth standing still while the air moved over its surface with this fearful velocity. A wise man, not reflecting that the atmosphere moved with the earth, proposed rising in a balloon, and waiting till the country to which he wished to go should be passing under him.

189. **Motion and Rest.**—Though we use the term rest in opposition to motion, it is obvious from some of the illustrations given that rest is merely a relative term, for not a particle of matter in the universe is at rest. Though when we are sitting still we call ourselves at rest, we are moving every hour, by the revolution of the earth on its axis, 1000 miles eastward, and 68,000 miles in our annual journey round the sun. Why, then, are we so insensible to these rapid motions? It is partly because the motions are so uniform, but chiefly because all things around us, our houses, trees, and even the atmosphere, are moving along with us. If we were moving along alone, even at a slow rate, while all these objects were standing still, we should be conscious of our motion, as we are when, as we ride along in a carriage, we see the objects at the road-side not moving along with us.

190. **A Comparison.**—The above can be made more clear and impressive by a familiar comparison. A man on board of a steamboat, by confining his attention to things within the boat, may, after a while, be almost un-

conscious of the boat's moving, if the water be smooth, though the boat may be going at the rate of fifteen miles an hour. If he be reading in the cabin he will think as little of his motion as he would were he reading in his parlor at home. If he should be blindfolded, and turned around a few times, it would be impossible for him to tell the direction in which the boat is going. Now it is with a man on the earth as it is with the man in the boat. He is unconscious of the motion of the earth for the same reason that the man in the boat is unconscious of the boat's motion. All objects around him are moving along with him, as the objects around the man in the cabin of the boat are moving along with him. We can carry the parallel farther. While the man sits in the cabin he knows not how fast the boat moves, nor even whether it moves at all. He must look out to decide this, and even then he may not be able to tell whether the boat moves, or whether he merely sees the water running by it. We often are actually deceived in this respect. A steamboat struggling against wind and wave may appear to those on board to be advancing when it is really stationary, or even when it is losing ground. So when we look at the sun we know not whether it is the sun or the earth that is moving. Mere vision, without reasoning on the subject, leads one to think that it is the sun that moves. For the same reason, if a child should be placed in a carriage for the first time without seeing the horses, but with its eyes fixed on objects at the road-side, he would probably think that all the fences and trees and rocks and houses are in motion.

191. **Absolute and Relative Motion.**—The motion of a body is said to be *absolute* when it is considered without relation to the position of any other body. Its motion is said to be *relative* when it is moving with respect to some other body. Absolute rest is unknown, for no body in the universe is known to be without motion. But a body may be relatively at rest, that is, in a fixed relative

position to other bodies. Every body is in a state of absolute motion, and yet it may be in a state of relative rest. All objects that appear to us to be at rest have a very rapid absolute motion. They appear to be at rest merely because they have the same rapidity and direction of absolute motion that we have ourselves. And all the motions which are apparent to the eye are only slight differences in the common absolute motions, of which, though they are so exceedingly rapid, we are entirely unconscious. Thus, if I stand still, and another at my side walks at the rate of three miles an hour eastward, we both of us have a common absolute motion of 1000 miles in every hour, and he merely adds three miles to his thousand—I move 1000 miles, and he 1003. So if I sit still in my parlor, and my friend travels eastward at the rate of 20 miles an hour, I move every hour 1000 miles, and he 1020. And if he travel westward at this rate he really travels slower than I do—he has an absolute motion eastward of 980 miles, and I of 1000. At the same time we are both whirling on in our annual journey around the sun at the rate of 68,000 miles an hour.

192. **Obstacles to Motion.**—As motion is naturally disposed to continue (§ 49 and § 184), whenever it is stopped it does not spend itself, but is stopped by obstacles. The principal of these obstacles are: gravitation; the resistance of opposing substances—solids, liquids, and gases; and friction. When a stone is thrown into the air its upward motion is gradually destroyed by the attraction of the earth and the resistance of the air. Observe, now, why it descends. It is from the action of one of the causes which arrested its upward flight—the attraction of the earth. In its descent it is retarded by the resistance of the air, as it was in its ascent. This retardation is very obvious in the case of substances which present a large surface to the air, as a feather. A small piece of lead will outweigh many feathers, and therefore, as its

quantity of matter is so much greater in proportion to its surface than that of a feather, it will fall to the ground much more quickly. That this is owing wholly to the resistance of the air can be proved with the air-pump.

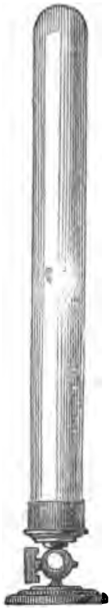


Fig. 128.

Suppose that you have a tall receiver, Fig. 128, on the air-pump, and a piece of lead and a feather are placed at its upper part in such a way that they can be made to fall at the same instant. Exhaust the air, and then let them fall. They will go down side by side, as represented by the figure, and reach the bottom of the receiver at the same time, because there is no air there to resist the progress of the feather. The toy called the water-hammer illustrates the same thing. When water falls through the air the resistance of the air tends to separate its particles, as we see in the falling of water thrown up by a fountain. In the water-hammer, which is a closed tube containing a little water and no air, when the water is made to fall from one end to the other, as there is no air to divide it, it falls as one mass, and gives a sharp sound like the blow of a hammer. An instrument essentially like this can be made with a thin glass flask. Put a little water in it, and, after heating it to boiling over a spirit-lamp, cork the flask tightly, and then leave the water to cool. As all the space above the water was filled with steam when the flask was corked, it is a vacuum now that the steam is condensed.

193. **Relation of Bulk to the Resistance of Liquids and Gases.**—You have already seen, in § 192, that the more surface a body has in proportion to its weight the greater is the resistance of the air to its motion. This truth, which applies to liquids as well as to airs or gaseous substances, explains the fact that small bodies meet with

proportionately more resistance than large ones. The body B, Fig. 129, you see is made up of eight cubes of the size of the cube a, that is, it has eight times the quantity of matter that a has. Now if B were moving through air or water, any of its sides pushing the water before it would meet with only four times the resistance that a side of a would, for its surface is only four times as large, and yet the body is eight times as large as a. And the greater the difference of size the greater is the difference of resistance. If B were a cube twenty-seven times as large as a it would meet with only nine times as much resistance. You see here the reason that shells and cannon-balls can be thrown much farther than bullets and small shot. The sportsman does not throw away his shot by foolishly aiming at birds at great distances, and yet shells and large cannon-balls can be thrown the distance of several miles. The difference is not in the degree of velocity which the powder produces, but in the resistance of the air. It is for the same reason that rain falls with greater rapidity than drizzling mist.

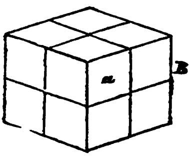


Fig. 129.

As liquids and aeriform substances resist solids in motion in proportion to the amount of surface which the solids present to them, so also when they strike against solids they cause motion in them in proportion to the amount of surface acted upon. Thus a violent wind could not move a lump of tin, but could blow along a sheet of it, or tear up a roofing of it if it got beneath. So clouds of sand are raised into the air in the deserts of Africa, although the particles are of the same material as stones, and therefore have the same specific gravity. For the same reason dust, feathers, the down and pollen of flowers, etc., are blown about, although they are heavier than the air. A pebble is moved more easily by a current of water than a stone, because it has a larger sur-

face, in proportion to its weight, to be acted upon by the water. For the same reason sand is moved more easily than pebbles, and fine mud than sand, though stones, pebbles, sand, and mud may all be of the same material. This explains why you will find mud where the current is slow, sand where it is faster, pebbles and stones where it is still faster, and where the current is exceedingly rapid you find nothing but large rocks—sand, pebbles, and stones not being able to resist its force. For the same reason, in the process of winnowing, the chaff is carried away by the wind; while the grain, presenting less surface in proportion to its weight to be acted upon by the air, falls to the floor.

In all the above cases the moving water or air may be considered as acting in opposition to the attraction of the earth, the latter pulling the substance down to the earth, and the former pushing it away from the earth. Of course, the more surface the water or air has to push upon the greater is the effect; and it is to be remembered that the attraction of gravity is as the quantity of matter, without any regard to amount of surface in the body attracted.

194. **Relation of Force to Velocity.**—It would seem at first thought that the motion produced in any body must be in exact proportion to the force producing it; that is, that twice the force which produces a given velocity would double that velocity, and three times would treble it, etc. This is true where there are no obstacles to motion, as in the case of the heavenly bodies moving in their orbits. But in all motions here upon the earth there are obstacles; and as reaction is always equal to action, the greater the velocity the greater is the reaction of the obstacle. If, therefore, you increase the velocity of any body, you not only have to communicate more motion to it, but you must overcome also the increased reaction. The rate of increase of force for increased velocities has been very accurately ascertained.

This I will explain. A boat moving from B to A, Fig. 130, we will suppose, displaces a quantity of water rep-

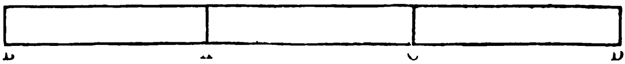


Fig. 130.

resented by the space between the two lines extending from B to A. Now if it move from B to C, it displaces twice the bulk of water B C; and as it is displaced in the same time that B A was, each particle is displaced with twice the velocity. Double the force is required to displace a double portion of water, and to do this with double the velocity the force must be doubled again. So if the boat is made to move three times as far in the same time, that is from B to D, three times the quantity of water is displaced, and each of these three portions, B A, A C, and C D, is displaced with three times the velocity. The force required, then, to do this is nine times that required to carry the boat from B to A in the same time. It is plain, therefore, that with velocities represented by the numbers 1, 2, 3, 4, etc., the forces requisite to produce these velocities must be as the squares of these numbers; viz., 1, 4, 9, 16, etc. This law is a very important one in a practical point of view. For example, it shows us how much larger a quantity of coal is required to produce in steamboats a high velocity than a moderate one. Its application too to the science of gunnery is important.

195. **Relation of Shape to Velocity.**—The resistance of air or water to a flat surface is greater than to a convex one, because the latter readily turns the particles to the one side and the other. So, also, a concave surface is resisted much more than a flat one, because the particles of the air or water can not so easily escape sideways. Fishes are of a spindle-like and slender shape, that they may have as little resistance as possible from the water. It is for this reason that a fish has no neck, for if it had

one the upper portion of its body would, from the resistance of the water striking against it, prove a serious impediment to rapidity of motion. Mankind have in some measure imitated the shape of fishes in their boats and ships. Boats which are intended to bear light burdens and go swiftly are made very long and narrow. The webbed feet of water-fowls, when they are moved forward, are folded up so as to meet with as little resistance as possible; but when they are moved backward they are spread out so as to press against the water a broad concave surface. For the same reason the wings of a bird are made convex upward and concave downward; and when it moves its wing upward it makes it cut the air somewhat edgewise, but in moving it downward it presses directly with the whole concave surface.

196. **Friction.**—Friction is generally an obstacle to motion. When we roll a ball, the more rough is the surface on which we roll it the greater is the friction and the sooner is the ball stopped. Friction lessens the rapidity of motion in machinery, and to prevent this as far as possible oiling and other expedients are employed. But sometimes friction is a cause of motion, as, for example, the friction of the driving-wheels of a locomotive upon the rails. In this case the wheel pushes backward on the rail at each successive point of contact. To make this clear, suppose a common wheel is deprived of its rim and is made to revolve on the ends of its spokes. The end of each spoke gives a backward push as it strikes the ground. Now the rim of a wheel makes the same pushes, but they are more numerous—they are continuous, being made by all the successive points in the rim. Sometimes the rails of a railroad are too smooth from frost or some other cause, and then sand is thrown upon them to give the locomotive a start. The sand serves to prevent the wheels from sliding by enabling them to get some hold upon the rails in their backward pushes.

197. **Friction of Liquids in Tubes.**—So easily does wa-

ter flow along that we should not at first view suppose that it would be delayed much from friction as it passes through pipes or along channels. But the retarding influence is considerable. An inch tube 200 feet long, lying horizontally connected with a reservoir, will discharge water not one quarter as fast as an inch orifice in the side of the reservoir. Sudden turns in a pipe should be avoided, because they occasion so much friction against the sides of the pipe and among the particles of water by disturbing the regularity of the current. In the entrance of the arteries into the brain, in order to prevent the blood from flowing too rapidly into this organ, there are sudden turns in the arteries to retard the blood; and in grazing animals, as there is special danger that the blood will flow too freely to the brain as the head is held down in eating, there is a special provision to prevent this in a net-work of arteries. If the arteries of the brain in such animals were straight tubes they would continually be dying of congestion of the brain or of apoplexy.

Friction in a small pipe is greater in proportion to its size than in a large pipe. In a pipe an inch in diameter water will not move more than one-fifth as fast as in a tube two inches in diameter. This may be made clear by Fig. 131, in which is represented the area of a small tube inside of the area of a tube of twice its diameter. Suppose the effect of the friction in the large tube to extend in to *a*. In the small one it will extend in as far, that is, to *b*. But *e a* is about five times as long as *e b*, so that there is full five times as much water clear of friction in the large tube as there is in the smaller one.

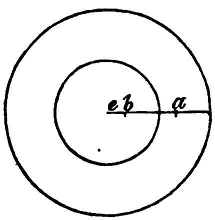


Fig. 131.

198. **Friction in Streams.**—The retarding effect of friction is very obvious in brooks and rivers. The water in the middle of a stream runs much more rapidly than it does near its banks. When a river is very shallow at

its sides the water there scarcely moves, though in the middle the water may be running at a rapid rate. A tide, therefore, flowing up a river, moves more freely near its banks than it does in the middle of the stream, because it meets with less resistance there from the downward current. Water moves less rapidly at the bottom of a river than it does at the surface. For this reason, if a stick be so loaded at one end as to stand upright in water, in the current of a river its upper end will be carried along faster than its lower end, and therefore it will incline forward, as in Fig. 132. As the sea rolls in over a beach, each wave at length pours over its crest and breaks, because the lower part of the wave is retarded by friction on the beach. Were it not for the constant retardation of friction at the sides and bottom of rivers, and at their bends, those rivers which have their rise at a considerable height above the level of the sea would acquire an immense velocity. Thus the Rhone, drawing its waters from 1000 feet above the level of the ocean, would pour them forth with the velocity of water which had fallen perpendicularly the same height, that is, at the rate of 170 miles an hour, did not friction continually diminish the velocity.

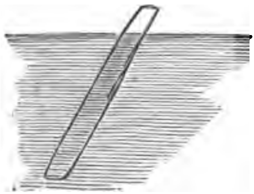


Fig. 132.

199. **Waves.**—Waves are generally formed by the friction of air upon water. Observe how they are formed. As soon as any portion of water is raised above the general surface it tends by gravity to fall to a level with the water around it, and in doing so the portion next to it is forced upward, forming another wave; and so one wave produces another, each one being smaller than the preceding, till at length the motion is wholly lost. This is always the process when the cause of the motion is a single impulse, as when a stone is dropped into the water. But when the waves are produced by a succession

of impulses, as when wind makes them, they are mostly of the same size. It is quite a common notion that the water moves as rapidly as the waves appear to do; but the water really remains nearly stationary, rising and falling, while merely the form of the wave advances. The same wave is made up continually of a succession of different portions of water, or rather it is a succession of different waves. This is very well illustrated by the waving of a rope or carpet. In an open sea a wave slopes regularly on either side; but when it comes near the shore, for the reason given in § 198, it grows more and more nearly perpendicular on the side toward the shore, till at length it falls over, and if it be very large the roar thus caused by its breaking is heard to a great distance.

200. **Height of Waves.**—"So awful," says Dr. Arnot, "is the spectacle of a storm at sea that it is generally viewed through a medium which biases the judgment; and lofty as waves really are, imagination pictures them loftier still. Now no wave rises more than ten feet above the ordinary sea-level, which, with the ten feet that its surface afterward descends below this, gives twenty feet for the whole height from the bottom of any water-valley to an adjoining summit. This proposition is easily verified by a person who tries at what height on a ship's mast the horizon remains always in sight over the top of the waves—allowance being made for accidental inclinations of the vessel, and for her sinking in the water to much below her water-line, at the time when she reaches the bottom of the hollow between two waves. The spray of the sea, driven along by the violence of the wind, is of course much higher than the summit of the liquid wave; and a wave, coming against an obstacle, may dash to a great elevation above it. At the Eddystone Light-house, when a surge breaks which has been growing under a storm all the way across the Atlantic, it dashes even over the lantern at the summit."

201. **Momentum.**—The momentum of a body is its

force when in motion. In estimating the momentum of any body two things must be considered—its velocity, and its quantity of matter or weight. A bullet fired from a gun has a vastly greater force, or power of overcoming obstacles, than one thrown by the hand, from its greater velocity. Now suppose the weight or quantity of matter to be increased ten times, and that it moves with the same velocity as before, it will have ten times as much force as before, and will overcome ten times as great an obstacle. For this reason a small stone dropping upon a man's head may do but little harm, while one ten times as large, falling from the same height, may stun and perhaps kill him. But if the large stone could fall with only one-tenth of the velocity of the small one, the effect of both would be the same. Let this example illustrate the rule for calculating the momentum of moving bodies, viz., multiply the quantity of matter into the velocity: Let the weight of the small stone be 1 ounce, and that of the large one 10 ounces. If they fall from a height of 16 feet the force with which the large one will strike will be expressed by 160 (16 × 10), that of the small one by 16 (1 × 16). Suppose, now, that by some force in addition to gravity the small one could be made to move ten times as fast as the large one, the force with which it would strike would be equal to that of the large one, and would be expressed by the number 160.

I will illustrate this in another way. Let *a* and *b*, Fig. 133, be two balls of clay of equal size hanging over a graduated arc. Now if *b* be let fall from the top of the arc, 6, on striking against *a* it gives half of its motion to *a*, and they both move on together. But how far will they go? To 3, on the other side of the arc. Why? Let the quantity of matter in each ball be called 1, and the mo-

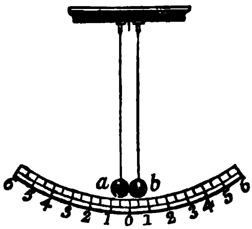


Fig. 133.

tion of *b* 6. The momentum will therefore be 6. Now the momentum of the two together will be the same after the blow as that of *b* was before it. But the quantity of matter is twice as great, and must be called 2. Therefore the motion must be represented as 3, to make the momentum 6 (2×3). But suppose that *b* is twice as large as *a*. Falling from 6, its momentum would be represented by 12 (2×6). After it has struck *a*, the momentum of the two together would be the same as that of *b* before the stroke; but the quantity being 3, the motion would be represented by 4. They would therefore move to 4 on the arc.

202. **Examples.**—A few examples illustrating momentum as being compounded of quantity of matter and velocity will suffice. If a musket-ball of an ounce weight were so much spent as to move with only a velocity of a foot in a second, its force would be so small that if it hit any one it would do no harm. But a cannon-ball weighing a thousand ounces moving at this slow rate would have a very great force—equal, in fact, to the momentum of an ounce ball moving 1000 feet in a second.—If a plank push a man's foot against a wharf he will scarcely feel it; but if the plank, instead of being alone, is one of a thousand planks fastened together in a raft, and the whole move with the same velocity, the force will be increased a thousand-fold, and the plank will crush the foot. So, also, if the one plank when alone should move a thousand times as fast as the whole raft, the same result would follow.—So soft a substance as a candle can be fired through a board from the momentum given to it by an immense velocity.—Perhaps there is no better example of the great force given to a substance by an enormous velocity than we have in the wind. So light a thing is air that people think of it as almost nothing. But let it be set in rapid motion, and the velocity gives to it a force, a momentum, which will drive ships upon the shore, throw over buildings, and tear up trees by the

roots. In this last example we see beautifully illustrated the meaning of the expression quantity of motion. In the moving air each particle does its share of the work in the destructive effects mentioned. Each particle, therefore, may be considered as a *reservoir* of motion, and the quantity of motion in any case depends upon the quantity which each particle has and the number of the particles.

203. **Production of Great Velocities.**—When there are no obstacles to motion great velocities may be produced by a single impulse. Thus at the beginning the Creator gave a single impulse to each of the heavenly bodies, producing enormous velocities, which continue unaltered year after year and age after age, because these bodies fly in their orbits through space where there is no resistance of any thing like air to retard the motion. But in all the motions that we see around us there are obstacles continually retarding them; and therefore no very rapid motion is produced by any single impulse, but a succession of impulses is required to accumulate sufficient momentum so to overcome the obstacles as to secure a great velocity. I will give a few examples in illustration. One of the best examples we have in the fall of bodies to the earth. You know that the greater the elevation from which a body falls the greater is its velocity, and therefore the greater the force with which it strikes. Why is this? If it fell because of a single impulse making it go toward the earth, this would not be the case, and if there were no air in the way the velocity would be uniform; but the resistance of the air would retard the velocity, so that if a number of bodies should receive the same impulse at different elevations, the one the farthest off would be the most retarded, and therefore come down slower than all the rest. In this case, the higher the elevation from which a man should fall the less would be the injury. But a body does not come to the ground by a single impulse, but by a succession

of impulses, or rather a continued impulse. Every moment that the body is coming down it is drawn upon by the attraction of the earth, and this continued action of the cause of the motion makes it continually increase in rapidity. It is on the same principle of continued action that a man lifts his hammer high when he wishes to inflict a heavy blow. In this case both gravitation and the muscular power of the arm exert their force on the hammer through the whole space. A horse in kicking does the same thing, and by the great length of the leg the velocity given to the foot by this continued action of the muscles is very great. An arrow is not shot by a single momentary impulse of the bow-string, but the string, by following it through a considerable space, gives it a continued impulse. The action of gunpowder upon a bullet issuing from a gun is apparently an instantaneous and single impulse, but it is not really so. The great velocity given to the bullet is given to it by the continued impulse of the expansive force of gases produced from the powder, and it therefore depends much on the length of the barrel. If this be short, the force of the powder is not confined long enough to the bullet to give it a great velocity.

204. **Arrest of Great Velocities.**—As a continued force is required to produce great velocities, so a continued resistance is necessary to arrest them. It is by the gradual or continued resistance of the air that the motion of a cannon-ball is destroyed. Now if instead of this gradual resistance any hard substance, as a block of granite, were opposed to the progress of the ball, it would be at once broken asunder. We see then the reason that a hard substance of moderate thickness does not offer so effectual a resistance to a body moving very rapidly as some substance of a more yielding kind and of greater bulk. For example, a bale of cotton will arrest a ball which would pass through a plank, for the cotton yielding easily permits the force of the ball to be felt and re-

sisted by a larger bulk, while the wood, not yielding, opposes but a small portion of its whole bulk to the force of the ball, and therefore does not arrest it; in other words, the momentum of the ball is communicated to a much larger quantity of matter in the cotton than in the wood. These principles afford a ready explanation of a feat which is sometimes performed. A man lies upon his back, and, having an anvil carefully placed upon his chest, allows some one to strike a heavy blow with a hammer upon the anvil, and no injury is received. Why? Because the momentum or force of the hammer is diffused throughout the bulk of the anvil, and then again through the bulk of the yielding chest. The man takes good care to have his lungs well filled with air at the moment of the blow, for this increases the bulk and elasticity of the chest, and thus promotes the diffusion of the momentum. If the blow of the hammer were received directly upon the chest great injury would be done, for the force would now be spent upon one small spot alone. —The principles above elucidated are applied by men instinctively in their common labors and efforts. You see a man catching bricks that are tossed to him. As he receives the bricks into his hands he lets his hands and the bricks move together a little way, so that he may gradually arrest the motion of the bricks. To do it suddenly would give him a painful lesson on momentum. So when a man jumps from a height he does not come to the ground in a straight position. This would cause a sudden and therefore a painful arrest of the motion of the whole body. To avoid this he comes to his feet with all the great joints of his body bent, so that the different portions approach the ground successively, his head having its motion arrested last.

205. **Communication of Motion in Elastic Bodies.**—Momentum is transferred from one body to another very differently in elastic from what it is in non-elastic bodies. As you saw in § 201, when one non-elastic body strikes

upon another the momentum is divided between them, and both move on together. Now if *a* and *b*, Fig. 133, were elastic bodies, as ivory balls, and *b* should be let fall against *a*, it would give all its momentum to *a*. Therefore *b* would stop, and *a* would move on to the same height from which *b* came. The reason is, that the velocity lost by *b* and received by *a* is just double what it would be if the balls were non-elastic. For the same reason, if *a* and *b*, being elastic, meet each other from equal heights on the arc, they will both rebound, and return to the same heights from which they came. But if non-elastic they simply destroy each other's momentum and stop. The effect produced in the former case is just twice as great as in the latter, as you may see by reckoning on the arc. For the same reason, too, if you have a row of elastic balls, as in Fig. 134, and let *a* fall from the point *i* upon *b*, it will stop there; and communicating all its momentum to *b*, this momentum will pass from *b* to *c*, and so on through all the row of balls to *e*, the last one, which will fly off to the point *h*, at the same height with *i*, the point from which *a* fell. If *b* be held still, and *a* be let fall upon it, *a* will rebound to the height from which it fell, for then the compressed elastic spring (§ 39) of each ball, as *b* is immovable, communicates all the motion to *a*. It is for this reason that an elastic ball, on being thrown against any thing fixed, rebounds. If what it is thrown against be perfectly elastic it rebounds with a force equal to that with which it is thrown.

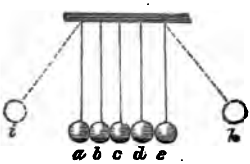


Fig. 134.

206. **Reflection of Motion.**—If an elastic body be thrown perpendicularly upon a surface it rebounds in the same path in which it is thrown. But if it hit the surface obliquely it is thrown off or reflected in a different direction. Thus a ball thrown from *b* upon *c*, Fig. 135 (p. 158), will return in the line drawn to *b*. But if

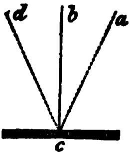


Fig. 135.

it be thrown from *d* it will be reflected in the line *c a*. Now the angle *d c b*, called the angle of incidence, is always equal to *b c a*, the angle of reflection. The same, you will find in other parts of this book, is true of sound and light and heat.

207. **Uniformity of Motion.**—Since motion, when once begun, is disposed to continue unless arrested by obstacles, it is naturally uniform both in its velocity and its direction. I will speak now only of velocity. Suppose a body to be set in motion, and to meet with no opposition from friction, or the resistance of air, or attraction, it would move on forever, and with the same velocity with which it began. Now precisely these circumstances we have in the motion of the heavenly bodies in their orbits. They are, it is true, under the influence of attraction, but in such a way, as you will soon see, as not to interfere with the uniformity of their motion. Were it not for this uniformity we should have no regularity of times and seasons. It is only by the uniform motion of the earth round the sun, and round its own axis, that we can calculate for to-morrow, or next week, or next year. If these motions were irregular it would throw confusion into all our calculations for the future and all our recollections of the past. We can measure time by nothing else but regular motion, and were there no regular motion we should have merely the very inaccurate measure furnished by our sensations. To measure time with accuracy we take some great and extensive uniform motion as our standard. Thus, the revolution of the earth around the sun we take as one division of time, and call it a year. We observe that during this time it whirls around on its own axis 365 times, and the time occupied by each of these revolutions we call a day.

208. **The Pendulum.**—Various modes of measuring time have been adopted by mankind. At first time was inaccurately divided by merely observing the sun. But

after a while man resorted to various contrivances to measure short periods of time with accuracy. All of these depend upon the uniformity of motion alone. The sun-dial measures time by the uniform movement of the shadow on its face, caused by the uniform movement of the earth in relation to the sun. The hour-glass measures time by the uniform fall of sand produced by the attraction of gravity. The best measurement of time is by the comparatively modern invention of clocks and watches, in which time is divided into very minute periods by the uniform motion of the pendulum or the balance-wheel. The pendulum furnishes an interesting example of motion kept up by the influence of gravity. It was not till the time of Galileo, less than three centuries ago, that its operation was understood and appropriated to the measurement of time. He observed that chandeliers hanging from lofty ceilings vibrated very long and uniformly after they were accidentally agitated, and the thought of the philosopher evolved from this phenomenon the most important results. Though it had been before men's eyes in some shape or other since the creation, it was reserved for Galileo to observe its significance, and the result is that the pendulum has become man's time-keeper over the whole earth.

209. **Explanation of its Operation.**—A pendulum consists commonly of a ball or weight at the end of a rod suspended so as to vibrate with little friction at the point of the suspension. Let *a b*, Fig. 136, represent such a pendulum. When it is at rest it makes a plumb-line hanging toward the centre of the earth. If it be raised to *c* and be left to fall, the force of gravity will not only carry it to *b*, but, by the accelerated velocity or accu-

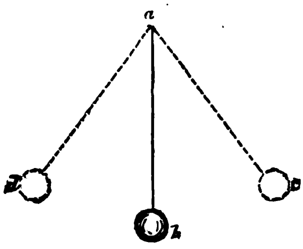


Fig. 136.

mulated momentum which it gives it in its descent, it will carry it to *d*. The same would be true of its return from *d*. And it would vibrate forever in this way if it could be entirely freed from the resistance of the air and friction. But, as it is, the pendulum left to itself gradually loses its motion from these obstacles. In the common clock the office of the weight is to counteract the influence of these obstacles, and keep the pendulum vibrating. In the watch the mainspring performs the same office to the balance-wheel.

The times of the vibrations of a pendulum are nearly equal whether the arc it describes be great or small.

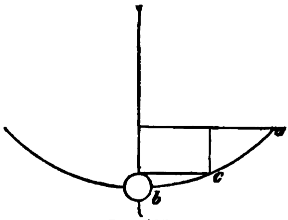


Fig. 137.

For when the vibration is a large one the velocity which the pendulum acquires in falling is greater than when the vibration is of small extent. The reason is that the higher it rises the more steep is the beginning of its descent. Thus *a c*, Fig. 137, is steeper than *c b*.

210. **Gridiron Pendulum.**—The longer a pendulum is the longer time does its vibration occupy. It requires a pendulum of the length of a little over thirty-nine inches to vibrate seconds. Cold weather, by contracting the

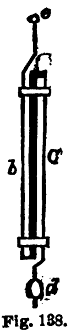


Fig. 138.

pendulum, makes it vibrate quicker than in summer, and so makes the clock go faster. Various contrivances have been resorted to in order to counteract the variation of length in pendulums by heat and cold, but what is called the gridiron pendulum is the best. In this pendulum an ingenious use is made of the fact that heat expands brass nearly twice as much as it does steel. A simple form of this pendulum is given in Fig. 138. The middle rod is made of brass, and the side rods, *b* and *c*, of steel. Suppose that the brass rod expands or increases in length half an inch.

The rod *c* would be drawn upward by it, and the rod *b* downward, each one quarter of an inch; but this effect is counteracted by the expansion of each steel rod, which is half that of the brass, that is, one quarter of an inch. The ball *d*, therefore, always retains the same distance from the point of suspension, *e*. In Fig. 139 you have a gridiron pendulum of a more compound character, a part of the bars being steel, and a part brass.


Fig. 139.

211. **Motion Disposed to be Straight.**—When a body is set in motion, if it be left to itself—that is, if nothing interfere with its motion—it will move in a perfectly straight line. It requires some interference from some force to bend the motion. You will readily see from the views which I have given you that there never is any motion that is, strictly speaking, straight, because every motion is in some measure compound; that is, each cause of motion is modified in its action by other causes of motion. But we can approximate very nearly to straight motion by making one cause preponderate very much over other causes. This I will illustrate. If we fire a bullet horizontally from a gun it is acted upon by three forces: the propulsive force of the powder, the resistance of the air, and the attraction of the earth. The action of the second of these is in direct opposition to the first, and therefore only retards the motion, and does not tend at all to turn it from its straight course. This is seen in the fact that the ball is turned neither to the right hand nor to the left. But the third force tends to make the ball bend its course toward the ground. It does this from the instant that the ball leaves the gun throughout its flight, but so slightly that practically we can consider the ball as going straight for short distances. When we take a long range we must make allowance for this bending down of the motion. Accord-

ingly, for the sake of precision, a double sight is provided in modern guns, as seen at A and B, Fig. 140. This you

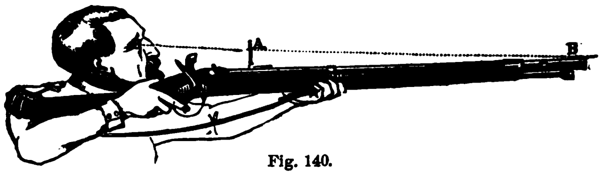


Fig. 140.

see secures the pointing of the gun a little above the level of the object aimed at, that level being indicated by the dotted line.

The greater is the propulsive force the more nearly to a straight line is the path of the propelled body. This may be seen very clearly in Fig. 141, representing the issuing of water at different points from a vessel. As pressure in a liquid is as depth, § 121, the force with which the water is thrust out is greater at C than at B, and at D than at C. The issuing stream, therefore, is most nearly straight at the lowest point, D.

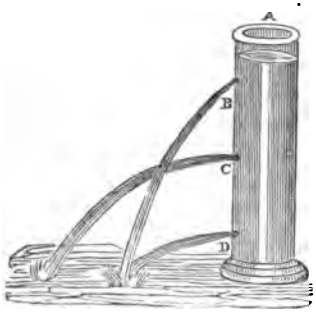


Fig. 141.

The motion of projectiles, thus alluded to, will be more particularly noticed farther on.

212. **Compound Straight Motion.**—We call that motion compound which is produced by two or more forces acting upon the body. This may be straight or curved. I will first speak of the straight. If a man attempt to row a boat straight across a river, the point which he will reach will not be directly opposite to that from which he started, but below. Two forces act upon the boat: the current tending to carry it straight down the stream, and his rowing tending to carry it straight across.

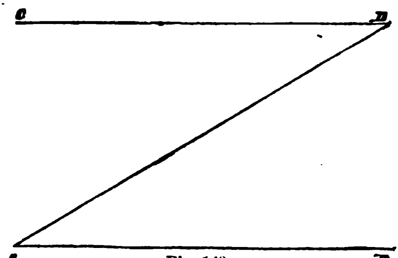


Fig. 142.

The boat will go in neither of these directions, but in a line between them. Let A B, Fig. 142, represent the bank of the river, from which he starts at A, with the bow of the boat pointing to C, on the opposite bank. Suppose now that in the time that it takes him to row across the current would carry him down to B if he did not row at all. He will in this time, by the two forces together, reach the point D, opposite to B, his course being the line A D. So if the wind blow upon a vessel in such a way as to carry it eastward, and a current is pushing it southward, the vessel will run in a middle line, viz., southeast. For the same reason if a boy kick a foot-ball already in motion, it will not be carried in the direction in which he kicks it, but in a line between that direction and the direction in which its former motion was carrying it. In swimming, flying, rowing, etc., we have examples of compound motion, the middle line between the directions of the forces always being taken by the body moved.

If we take Fig. 142, illustrating the movement of the boat, and draw two lines, one from A to C and the other from B to D, we shall have the parallelogram A C D B, Fig. 143, in which the line A C represents the force of the rowing, A B the force of the current, and A D the path of the boat. You see,

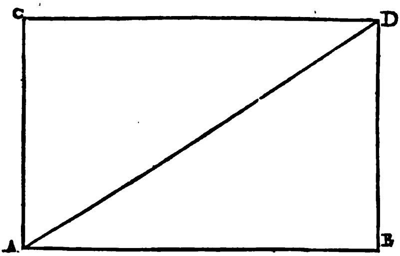


Fig. 143.

then, that if we wish to find in what direction and how far in a given time a body acted upon by two forces will move, we are to draw two lines in the direction of these forces, and of a length in proportion to the distances to which they would move it in that time; then by drawing two lines parallel to these we shall have a parallelogram, and the diagonal of this will represent the distance and the course of the moving body. If a body be acted upon by two equal forces and at right angles to each other, the figure described will be a square, as you see in Fig. 144.

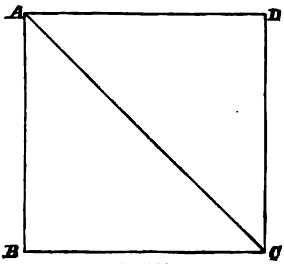


Fig. 144.

If they vary from being at right angles to each other the figure will vary in the same proportion from the square figure, as seen in Figs. 145 and 146. In the three figures A B and A D represent the two forces, and A C the resulting motion.

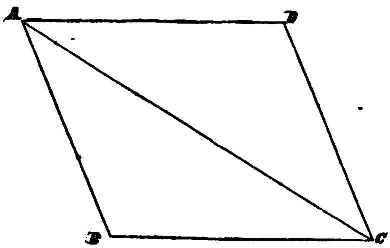


Fig. 145.

You observe by these diagrams that the nearer the two forces come to being in the same direction the farther will they move the body. You see this in the different lengths of the diagonals in

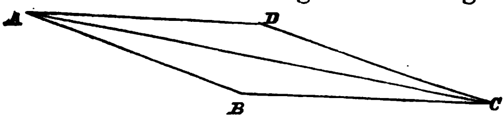


Fig. 146.

Fig. 144 and Fig. 146. The more nearly, therefore, the wind coincides with the current the more rapidly will a

vessel be carried along before the wind. When, on the other hand, the angle at which two forces act upon a body is much greater than a right angle, they will propel it but a small distance. Thus if two forces act on a body in the directions D A and D C, Fig. 147, they will move

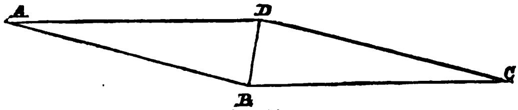


Fig. 147.

it only the distance represented by the diagonal D B. This diagram represents the motion of a vessel sailing almost directly against a current by a wind the force of which is equal to that of the current, while Fig. 146 represents the motion of a vessel where wind and current being of equal force very nearly coincide. In the above diagrams I have supposed the forces to be equal; but the same truth can be shown in regard to unequal forces as seen in Fig. 143.

213. **Curved Motion.**—No single impulse can produce a curved motion. Neither can two or more impulses communicated at one time. In both of these cases the motion would be in a straight line. Curved motion may be produced by two forces, one of which gives it a single impulse, and the other acts upon it continuously. A familiar example you have in a ball whirled around at the end of a string. You can give it an impulse, and then, holding it in your hand, let it whirl. Here the impulse you give the ball is one force, and the tension of the string is the other, the latter acting continuously. Your hand holding the end of the string is the centre about which the motion revolves; the impulse which you have given the ball tends to make it fly away from the centre in a straight line, and hence is called the *centrifugal* force; the tension of the string keeps it from thus flying off, and so is called the *centripetal* force. When the earth, at the creation, was put in motion it

would have moved in a perfectly straight line, were it not constantly drawn toward the sun by attraction, the continuous action of this latter force being the same as the tension of the string in the case of the whirling ball. The force of attraction, then, is the centripetal force of the earth, and the impulse which was given to it by the Creator in the beginning is its centrifugal force; and, balanced between these two forces, the earth and all the heavenly bodies move uniformly onward in their orbits. The centrifugal force you see in these illustrations is simply the tendency of motion to a straight line from the inertia of matter; and this is constantly counteracted by the centripetal force.

214. **Illustrations of Centrifugal Force.**—When a wet mop is whirled the water flies off in every direction by its centrifugal force. On the same principle a dog, coming out of the water, shakes off the water by a semi-rotary motion.—When a suspended bucket of water is turned swiftly around the water rises high on its sides, and leaves a hollow in the middle. It is the tendency to fly away from the centre of motion that causes this.—Large wheels, revolving with great velocity, have been broken by the centrifugal force of its particles, and hence the necessity of having such wheels made very strong. The immense grindstones used in gun-factories have sometimes been broken through in the middle, or have flown into pieces from the same cause.—A man riding horseback on turning a sharp corner inclines his body toward the corner, to avoid being thrown off by the centrifugal force. So, in the feats of the circus, a man standing on a horse running at full speed around the ring inclines his body strongly inward, as you see in Fig. 148 (p. 167). The horse also instinctively inclines in the same direction for the same reason. If the rider finds himself in danger of falling, by making the horse go a little faster, thus adding to the centrifugal force, the difficulty is relieved.—The centrifugal force is made use of

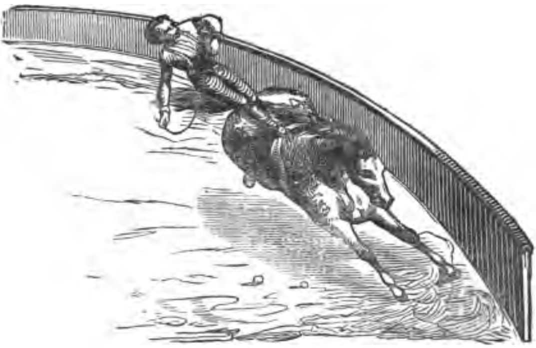


Fig. 148.

in milling. The grain is admitted between two circular stones by a hole in the centre of the upper one, and as the stone revolves it constantly moves toward the circumference, and there escapes as flour.

215. **Bends in Rivers.**—We see the operation of the centrifugal force in the bends of rivers. When a bend has once commenced in a river it is apt to increase, for as the water sweeps along the outer bank of the bend it presses strongly against it, just as the water in the whirled bucket, § 214, presses against its sides, by its centrifugal tendency, or, in other words, its tendency to assume a straight motion. Of course the result is a wearing away of this outer bank, and in proportion to the looseness of the material of which it is composed and the velocity of the river's current. And when one bend is formed another is apt to form below, but in an opposite direction. The water, by sweeping along the bend *a*, Fig. 149, is directed by it toward the opposite bank at *b*, and makes a bend there also.

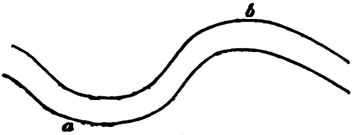


Fig. 149.

It is in this way that a river, running through a loose soil,

the Mississippi, for example, acquires a very serpentine course. As the water in the whirled bucket rises around the sides, so in the river the water will be higher against the bank *a* than on the opposite side. Eddies and whirlpools are produced on the same principles, when water is obliged to turn quickly around some projecting point. If a current were moving swiftly along the shore *a* toward the point *b*, Fig. 150, it would be directed outward by the resistance of this projection, and so a depression would be left at *c*, just behind it, and this depression would be surrounded by a revolving edge of water.

Fig. 150.

216. **Application of the Centrifugal Force in the Arts.**—Much use is made of the centrifugal force in the arts, but I will give but two examples. In the art of pottery the clay is made to revolve on a whirling table, the workman at the same time giving the clay such shape as he chooses with his hands and various instruments. In doing this he constantly has reference to the centrifugal force, giving the table a velocity proportioned to the amount of this force which is needed in each stage of the operation. The most beautiful application of this force that I have ever witnessed is in the manufacture of common window-glass. The glass-blower gathers up on the end of his iron tube a quantity of the melted glass, and blows it out into a large globe. When it is of sufficient size and thinness he places it on a rest, as you see in Fig. 151 (p. 169). A second man now comes with a rod having some melted glass on the end, and attaches this to the globe at a point opposite to that where the tube of the first man is joined to it. There now comes a boy, and, giving this tube a quick blow, severs its connection with the globe, leaving a hole in the globe where the glass breaks out. The second man, having the globe attached to his rod, carries it to a blazing furnace, and resting the rod on a bar at its mouth, puts the globe directly into

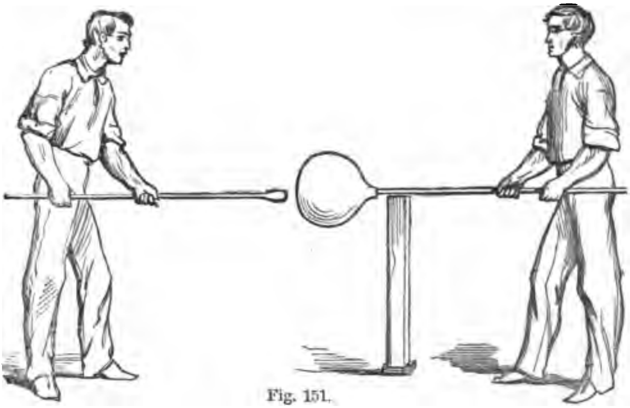


Fig. 151.

the flame. The glass is soon softened, and he whirls the globe continually around. The hole in the globe enlarges by the centrifugal force, and at length by this force the globe is changed into a flat, circular disk. Panes of glass which are called bull's-eyes are cut from the centres of these disks.

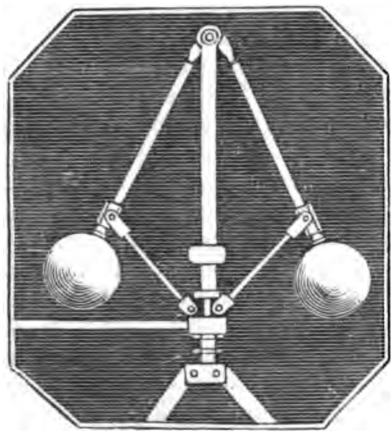


Fig. 152.

217. **Steam-Governor.**—The operation of the centrifugal force is beautifully exemplified in this regulator of the steam-engine. It consists of two heavy balls, Fig. 152, suspended by bars from a vertical axis, the bars being connected to the axis by hinges. The bars have also a hinged connection

at their lower ends with two smaller bars, and these latter have a similar connection with a collar that slides up and down on the axis. Now the faster the axis turns the farther the balls fly out from it, from the centrifugal force, and the higher the collar slides up on the axis. From the collar extends, as you see, a lever. This is connected with a valve in the steam-pipe, and so regulates the amount of steam that enters the working part of the engine. The object of this ingenious contrivance is to make the engine regulate its own velocity. When it is not working too fast the valve in the steam-pipe is wide open. But the moment that it works too rapidly the balls extend out far from the axis, so that the collar rises, and by the lever partly closes the valve. Less steam, therefore, can come to the engine, and the engine working in consequence less rapidly, the balls fall again, opening the valve. You see, then, that the regulation of this valve by the governor effectually prevents the action of the engine from becoming too rapid.

218. **Shape of the Earth Influenced by the Centrifugal Force.**—If the potter should make a ball of soft clay revolve rapidly around on a stick run through it, the ball would bulge out at the middle, where the centrifugal force is greatest, and would be flattened at the ends where the stick runs through it. This is precisely what has happened to the earth. At the equator, where the centrifugal force is greatest, it has bulged out about thirteen miles, while it is flattened at the poles. This shape was of course assumed before the earth became solid. In Fig. 153 we have the shape of the earth represented, N S being the polar diameter, and E E′ the equatorial diameter. The tendency to take this shape from the centrifugal force may

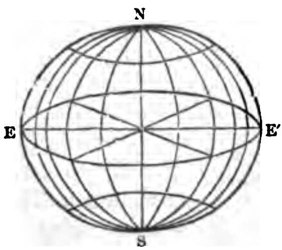


Fig. 153.

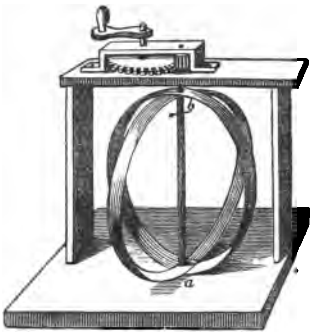


Fig. 154.

be illustrated by the instrument represented in Fig. 154. It consists of a set of circular hoops of brass, with an axis, *b a*. The hoops are fastened to the axis at *a*, but are left free at *b*. By a little machinery at the top they can be made to revolve rapidly, and bulging out at the sides by the centrifugal force, they slide down on the axis at *b*.

219. **Projectiles.**—I have already spoken of projectiles in § 211. You saw there that any body, as a cannon-ball, which is projected horizontally, falls to the earth in a curved line. Two forces act on the ball; viz., the projectile force given by the powder and the force of gravitation. The force of gravity being always the same, the shape of the curve which the projected body describes must depend on the force with which it is projected. This is very strikingly exemplified in the curves described by the different streams of water in Fig. 141. But whether the projectile force be great or small, the moving body thrown horizontally will in every case reach the ground in the same time. Thus if two cannons stand side by side on a height, one of which will send a ball a mile and the other half a mile, the two balls, if fired together, will reach the ground at the same instant, though at first thought it would seem that the ball which travels twice as far as the other would take a longer time to do it in. This is because the *horizontal* force of the ball does not oppose in the least the *downward* force of gravity. If it were thrown upward instead of horizontally, the projectile force would be opposed to gravity, and in proportion as the direction came near to being vertical. As horizontal force does

not interfere with the action of the force of gravity, it follows that a ball dropped at the instant at which another is fired will reach the ground at the same instant that the fired ball does. This can be made clear by Fig. 155. Suppose it takes three seconds for a ball to fall

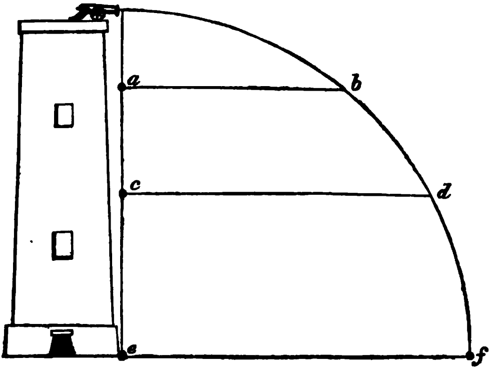


Fig. 155.

from the top of a tower to its foot. In the first second it falls to *a*. The ball projected horizontally from the cannon, being operated upon by the same force of gravity, will fall just as far, and will be on a level with it at *b*. Both balls fall farther and farther each second, both being accelerated in the same degree because it is done by the same force. The projected ball will reach *d* when the falling ball is at *c*, and the plain at *f* when the falling ball is at *e*, the foot of the tower. The same holds true in all cases. A bullet dropped from a level with the barrel of a gun, paradoxical as it may seem, will fall to the ground no sooner than one which is shot from the gun.

220. **All Falling Bodies really Projected.**—When a body falls from any height, it does not, as you have already seen in § 187, fall in a straight line, as it appears to do. It falls in a curved line, for, like all projectiles, it is acted upon by a horizontal force as well as the force of gravity. But what is this horizontal force? It is the

motion which the body has in common with the earth in its rotation on its axis. In this rotation the height from which the body falls goes to the eastward 1500 feet in a second. If, therefore, the body did not partake of the motion of the earth, and went to the ground in a *straight* line in a second, it would be when it reached the ground 1500 feet westward from the foot of the height from which it fell. But it does partake of the earth's motion, and goes eastward as fast as the height does, and so describes the curved line of a projectile.

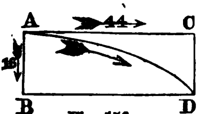


Fig. 156.

Suppose a ball falls from a height A, Fig. 156, and in a second of time that height passes to C. The forward or projectile force would tend to carry the ball to C, and the force of gravity would tend to carry it to B. But both forces acting together, it pursues a middle path, and this path is a curved line, because one of the forces is a continued force, § 213. For the same reason, if a ball be dropped from a railway car in motion, and it takes a second for it to fall, it will be at the end of that second just under that part of the car from which it fell. Although the car may have moved a considerable distance, the dropped ball, partaking of its motion, goes along with it in its fall. So a ball dropped from a mast-head when a ship is in motion goes along with the ship in its fall. The ball in each of these cases describes in its fall a curved line.

221. **Motion in Orbits.**—Why is it, let us ask, that a cannon-ball shot horizontally from some great height will not revolve around the earth like the moon. It has the same two forces acting upon it as the moon has—viz., a projectile force, and the attraction of the earth—and both ball and moon describe a curve in their motion. But the curve of the ball bends to the earth, while that of the moon ever sweeps around the earth. Why is this? First, there is the resistance of the air continually retarding the velocity of the ball. But, secondly, even if

the ball could be projected from an elevation sufficiently high to be outside of the atmosphere, the force of the projection would not be great enough. We know, from the rate of progress of the heavenly bodies in their orbits, that it would require an immense velocity to keep the ball from being brought to the earth by its attraction. The Creator of these worlds, when he launched them into their orbits, gave them precisely that impulse which is needed to balance the centripetal force of attraction, and so they pursue a middle course between the two directions in which these two forces tend to carry them. And as their velocities have never been retarded by the resistance of air or any other substance, they have been ever the same from the beginning.

CHAPTER XI.

THE MECHANICAL POWERS.

222. **Machines not Sources of Power.**—The Mechanical Powers, as they are termed, are six in number—viz., the Lever, the Wheel and Axle, the Inclined Plane, the Screw, and the Wedge. They are not, strictly speaking, powers; for, as you will see in the course of our investigation, they are merely means of applying power to advantage, and are not in reality sources of power. The true sources of power are the causes of motion treated of in § 181. The instrument or machine can not create power, and the only use of all the variety of tools and machinery is to enable us to *apply* power in such a manner, with such a velocity, and in such a direction, as to effect the objects which we have in view. The term Mechanical Power, then, is not strictly proper as applied to those contrivances which commonly have this name; but the term is in so general use that it would not be well to alter it.

Every instrument, however simple and insignificant, and every machine, however large or complicated, is an example of some one of the six Mechanical Powers, or of a combination of them. I will proceed to consider each of these separately. In doing this certain terms will be used which I will first explain. *Power* is the force by which a machine or instrument is moved. *Weight* is the resistance to be overcome. If the resistance be in some other form than that of weight it is called technically by this name. So what is called Power may be in the form of weight. The *fulcrum* is the point on which the instrument or machine is supported while it is in motion.

223. **The Lever.**—The Lever is the most simple of all the Mechanical Powers, and is therefore in universal use. Though the savage makes use of but few tools in comparison with the civilized man, he uses the lever almost constantly in some form or other. The wedge is the only one of the other Mechanical Powers that he uses to any great extent. Levers are of three kinds, which I will notice separately.

224. **Lever of the First Kind.**—In the lever of the first kind the fulcrum or prop is between the weight and the power. The common crow-bar or hand-spike is a familiar example, as seen in Fig. 157—the stone, S, or other heavy body to be moved being the weight, the stone or block of wood, F, on which the bar rests being the fulcrum, and the pressure of the hand, H, the power.

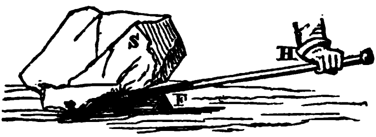


Fig. 157.

The nearer the fulcrum is to the weight, or the farther is the power from the fulcrum, the greater is the force of the lever. This may be illustrated on Fig. 158. Here the short arm of the lever, as

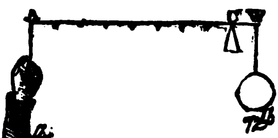


Fig. 158.

it is called, C W, is one eighth of the length of the long arm, A C. If the weight hanging at the end of the short arm be 72 pounds, a weight of 9 pounds, or the force of a hand amounting to this, will balance it at the end of the long arm. But if the power should be applied at only four times the distance from the fulcrum at which the weight is, then it would require a force of 18 pounds to balance the 72 pounds on the short arm. Similar variations can be made by altering the length of the short arm. The power and the weight will balance each other if the weight multiplied by the length of the short arm, and the power multiplied by the length of the long arm, give equal products.

225. **Scales and Steelyards.**—In the common scale-beam we have a lever, the two arms of which are equal, and therefore equal weights suspended at the ends balance. If they be not exactly equal, a heavier weight will be necessary on the shorter arm than on the longer. The inequality will injure the buyer if the prop be too near the scale in which the weights are placed, and the seller if it be too near that which holds the article to be sold. Any difference can be easily detected by changing the places of the article and the weights. Whenever cheating is practiced by the "false balance," it is of course done in a small way, to avoid any observation by the eye of the inequality of the two arms of the scale-beam, and the weight of the scale hanging from the shorter arm is made a little greater than that of the other, so that they may balance. Scales may be rendered very accurate by making the fulcrum or pivot of hardened steel, and of a wedge shape, with a sharp edge, in order to avoid friction as much as possible. The steelyard differs from the scale-beam in having the arms of different lengths. The principles on which this instrument is constructed were developed in what I said of Fig. 158. When either with the balance or the steelyard two weights balance each other the centre of the weights and the apparatus taken

together is just over the fulcrum, § 195. We see in this, the reason that it is necessary to have the prop near the large weight when we wish to balance it by a small one.

226. **Other Examples.**—Scissors are double levers of the first kind. The fulcrum is the rivet, the weight or the resistance to be overcome is the article to be cut, and the power is applied to the long arms of the levers by the fingers. With large shears hard substances can be cut. Even plates of iron are cut like paper by shears which are worked by a steam-engine.—Pincers are double levers. The hinge, or rivet, is the fulcrum.—The common hammer, as used in drawing nails, is a good example of the power of this kind of lever. Though crooked, it acts in the same way with a straight lever. The fulcrum is the point on the board where the hammer rests, and this is between the resistance to be moved, the nail, and the power, that is, the hand which grasps the handle.

227. **No Gain of Power in this Lever.**—I will now illustrate the truth that there is no gain or saving of power in this lever, though at first thought it would seem that there is. Let *a b*, Fig. 159, represent a lever, and *e* its fulcrum. Let the arm *a e* be twice as long as *e b*. A pound, therefore, suspended from *a* will balance two pounds at *b*. If, now, when the weights are suspended, the long arm be raised so that the lever shall be in the position represented by the line *c d*, and then let go, the one pound at *c*, balancing the two pounds at *d*, will bring the lever again to the position *a b*. It will be perceived that the end of the long arm of the lever moves through the space *a c*, which is larger than *b d*, through which the end of the short arm moves, in the same time. The one-pound weight,

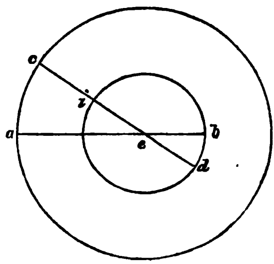


Fig. 159.

in fact, falls two feet in raising the two-pound weight one foot, and it moves twice as far as a one-pound weight suspended at *i* would. If a one-pound weight could raise a two-pound weight without thus moving through twice as much space we might then say that there is an actual gain of power in the lever. But it evidently makes no difference whether one pound moves through two feet or two pounds through one foot; the force is the same in both cases. For the momentum or force of a moving body is in proportion to its weight and velocity, § 201; and therefore the pound weight, moving through two feet, has as much momentum as the two-pound weight moving through one foot in the same time. The small weight does the same amount of work that the larger one would by moving twice as far in the same time as the larger, just as a boy, who carries a load half as large as a man, will do as much work as the man if he carry it twice as fast.

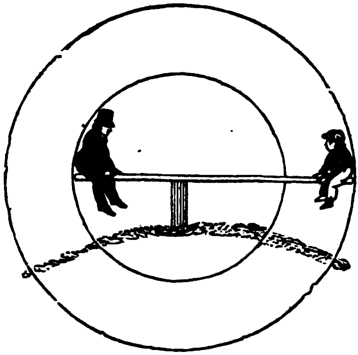


Fig. 160.

228. **The See-Saw.**—We see the same thing illustrated in the see-saw, Fig. 160. The man, being much heavier than the boy, is nearer the prop, and as they move up and down the boy passes over a much larger space than the man, describing an arc in a much larger circle.

229. **Archimedes's Lever.**—Archimedes said that if he could have a lever long enough and a prop strong enough he could move the world by his own weight. But he did not think how far he would have to move to do this, from the vast difference between his weight and the

weight of the earth. "He would have required," says Dr. Arnot, "to move with the velocity of a cannon-ball for millions of years to alter the position of the earth by a small part of an inch."

230. **An Analogy.**—You will remember that in the case of the Hydrostatic Paradox, the Hydrostatic Bellows, and Bramah's Press (§ 131, § 132, and § 133), great effects are produced by a small power. But this small power has to execute an extensive motion in order to produce these effects. Thus, as stated in § 132, if the area of the top of the Hydrostatic Bellows be one thousand times the area of the tube, though the water poured into the tube will raise a very great weight on the bellows, the water in the tube must fall ten inches in raising the weight the hundredth part of an inch. So when the pressure of the hand on the long arm of a lever moves a great weight, as a heavy stone, the weight is moved but a little, while the extent of the hand's motion is comparatively very great.

231. **Lever of the Second Kind.**—In the second kind of lever the weight is between the fulcrum and the power, as you see in Fig. 161. The same rule of equilibrium applies here as in the case of the lever of the first kind. The 72 pounds of weight can be sustained by 8 pounds of power, because the power acts on the lever at 9 times the distance from the fulcrum that the weight does, for $1 \times 72 = 9 \times 8$. The common wheelbarrow, Fig. 162 (p. 180), is an example of this kind of lever. The point at which the wheel presses on the ground is the fulcrum, and the weight is the load, its downward pressure from its centre of gravity being indicated at M. Of course the nearer the load is to the fulcrum the easier it is, on starting, to raise the handles.

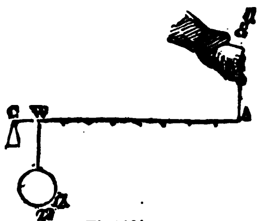


Fig. 161.


Fig. 162.

The crow-bar can be used as a lever of this kind when its point is placed beyond the weight to be raised. The chipping-knife, Fig. 163, is another example. The end, F, attached to the board, is the fulcrum, the hand pressing at P the power, and the resistance of the substance R, which is to be cut, is the weight. Nut-crackers have a similar arrangement. In shutting a door by pushing it near its edge we move a lever of this kind. The hinge is the fulcrum, and the weight is between this and the hand.

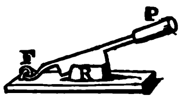


Fig. 163.

We see, then, the reason that the slight push of a hand shutting the door may even crush a finger when caught in it at the side where the hinges are. The finger is a resistance so near the fulcrum that the power moving through a great space acts upon it with immense force. The same explanation applies to the severe bite of the finger when it is caught in the hinge of a pair of tongs. The oar of a boat is a lever of this kind, the weight to be moved being the boat, which is between the power, the hand of the rower, and the fulcrum, the resisting water.

232. **Lever of the Third Kind.**—In the third kind of lever the power is between the fulcrum and the weight, as seen in Fig. 164. In the first two kinds of lever the power may be less than the weight, but in this the power must always be greater than the weight. This lever has,

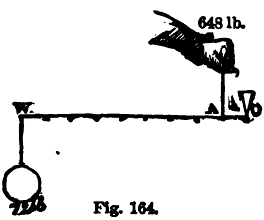


Fig. 164.

then, no mechanical advantage, as that expression is commonly used. Applying the same rule here as in the other levers, see what is the result. If the weight, as in Fig. 164, be 9 times as far from the fulcrum as the power is, it will require a power equal to a weight of 648 pounds to sustain a weight of 72 pounds, for $9 \times 72 = 1 \times 648$.

233. **Examples.**—When a man puts his foot against the end of a ladder, and raises it by taking hold of one of the rounds, the ladder is a lever of this kind. It is evident that he spends his force upon it at a great mechanical disadvantage, for the power is applied much nearer to the fulcrum than the weight of the ladder, taken as a whole, is. If you push a door to by placing your hand very near the hinges, you do not shut it as easily as when you take hold of it at its edge. In the first case it is a lever of the third kind, and the hand moves through a small space, and therefore must exert a considerable force; while in the latter case the door is a lever of the second kind, and the hand, moving through a greater space, puts forth less force. When we use a pair of tongs we use a pair of levers of the third kind. They are an instrument in which convenience rather than power is needed. We can not grasp any thing very firmly with them because the power is so much nearer to the fulcrum than the weight to be lifted. For this reason a pinch with the ends of the tongs is nothing compared with one in the hinge. The most beautiful example of this lever we have in the moving apparatus of animals. Take, for example, the principal muscle which bends the elbow, as represented in Fig. 165 (p. 182). This comes down from the shoulder in front of the bone of the arm, and is inserted just below the elbow-joint into one of the bones of the forearm. It pulls upon the forearm very near the fulcrum, which is the elbow-joint, and so acts at a great mechanical disadvantage. The object of this arrangement is to secure quickness of movement, which is here, as in almost all muscular motions, of more import-

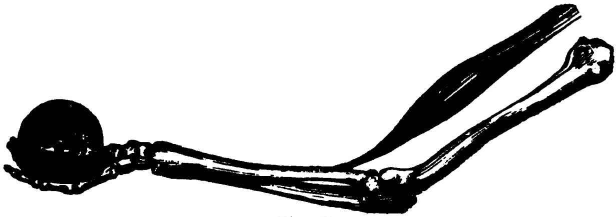


Fig. 165.

ance than great strength. When great weights are lifted the fact that the muscles act at such mechanical disadvantage makes the exhibition of power wonderful.

234. **Compound Levers.**—When several levers are connected together we call the whole apparatus a compound lever. Let each of the levers in Fig. 166 be 3 inches long, the long arms being 2 inches,

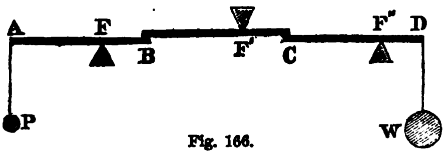


Fig. 166.

and the short ones 1 inch. One pound at A will, according to the rule, balance 2 at B, and 2 at B will balance 4 at C, and 4 at C will balance 8 at D. Therefore 1 pound at A will balance 8 pounds at D. And you see that an equilibrium is effected when the power is to the weight as the product of all the short arms is to the product of all the long arms. The compound lever is used in weighing heavy loads—as hay, coal, etc. You have a representation of the arrangement in Fig. 167. The load, W, stands on a platform, A B, which rests upon two levers, E D

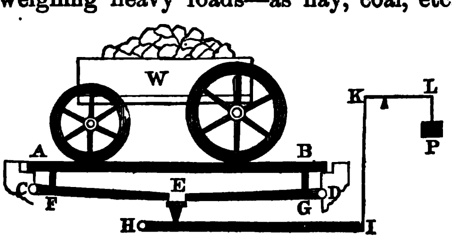


Fig. 167.

and E C. The long arms of these levers are E G and E F, and the short arms are G D and F C. The ends of the long arms press upon the fulcrum of the lever, H I. The pressure is now transmitted from the end of the long arm by the rod, I K, to a small lever, K L, where a small weight or power, P, balances the weight of the heavy load, W. The two objects secured by this arrangement are accuracy and the occupation of a small space.

235. **Wheel and Axle.**—The mechanical power next in simplicity to the lever is the Wheel and Axle. The most familiar applications of this power we see in drawing water and in raising heavy articles in stores. The principle of this power is the same as that of the lever, as may be shown in Fig. 168, which represents a section of the wheel and axle. The power, P, hangs by a cord which goes round the wheel, and the weight, W, by a cord around the axle. We may consider the power as pulling on a lever represented by A B, the long arm of which is A C, and the short arm B C. You see that the wheel and axle, then, may be viewed as a constant succession of levers, and it is therefore sometimes called the perpetual lever. And the same rule of equilibrium applies here as in the simple lever.

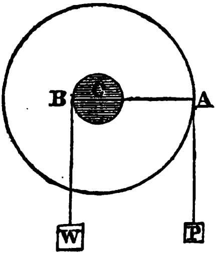


Fig. 168.

236. **Windlass.**—In the common windlass the power is applied to a winch or crank, D C B, Fig. 169, instead of a wheel. In estimating the power of this arrangement B C must be considered the long arm of the lever, and half of the diameter of the axle, B A, as its short arm.

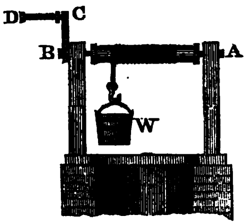


Fig. 169.

237. **Capstan.**—In the capstan, represented in Figs.

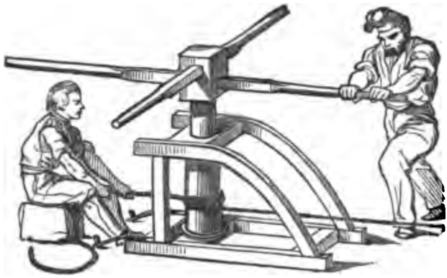


Fig. 170.

170 and 171, the axle is in a vertical position. The top of it is pierced with holes, into which levers are introduced. In Fig. 170 you see the instrument as it is commonly used in moving buildings. Sometimes horse-power is applied at the ends of the levers. Great power is exerted by this instrument; but we have the same fact here as in all cases where a small force produces a great effect—the effect is slow, and the force passes over a great space in producing it. The moving of a building a foot requires many circuits of the horse around the axle. Fig. 171 gives us the capstan as it is commonly on board ship. The head of it is circular, with many holes for levers, so that many men can work together in raising a heavy anchor.

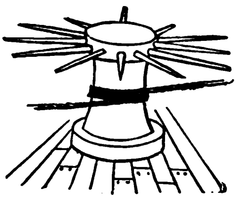


Fig. 171.

238. **Fusee of a Watch.**—In the fusee of a watch we have a wheel and axle of a peculiar construction. When we wind up a watch the chain is wound around the spiral pathway on the fusee, B, Fig. 172, and at the same time the spring is coiled up tightly in the round box, A. The spring, in gradually uncoiling itself, turns this round box around, and thus pulls upon the chain, *c*, making the fusee to revolve, and so give motion to other parts of the machinery. Now the spring, in its effort to

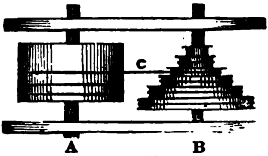


Fig. 172.

uncoil, acts strongest at first; and therefore if the fusee were of uniform size the watch would go fastest when first wound up, and go gradually slower as it run down. This difficulty is obviated by giving the power a small wheel to pull on at first, and gradually enlarging the wheel as the spring uncoils. This is because, in order to produce a certain effect on a given weight by a power, the less the power is the longer must be the arm of the lever on which the power acts.

239. **The Pulley.**—The third mechanical power is the Pulley. Pulleys are *fixed* or *movable.* In Fig. 173 you have a fixed pulley. There is no mechanical advantage in this pulley, for its action may be conceived of as the action of successive levers of equal arms, B F and A F, and therefore equilibrium requires an equality of the power and weight. But this pulley is often a great convenience. For example, a man can raise himself or some weight to any desired elevation, as seen in Fig. 174. It is used also in effecting descents.

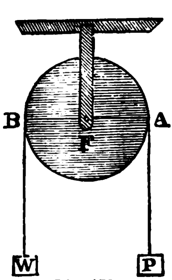


Fig. 173.

With two fixed pulleys a horizontal force may be used in raising a weight vertically, as seen in Fig. 175. In using a fixed pulley either one or the other of two objects is attained — applying force where we could not otherwise apply it, and changing the direction of its application.

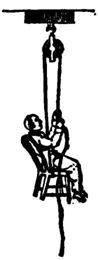


Fig. 174.


Fig. 175.

240. **Movable Pulley.**—You have a representation of a movable pulley in Fig. 176 (p. 186). It is evident here

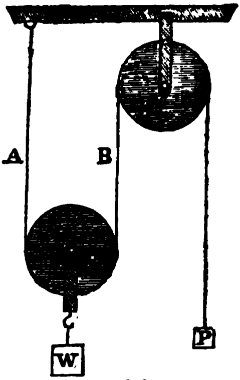


Fig. 176.

that the force of the weight is equally divided between the cords, A B, so that the cord B, extending over the fixed pulley, needs to have a weight, P, but half of the weight W to balance it. A movable pulley is sometimes called a "runner," and a fixed pulley is commonly connected with it, in order to give the desired direction to the force. Many pulleys are often connected together in various ways, as seen in Fig. 177. It is easy to estimate in such cases the relation of the power to the weight on the principles

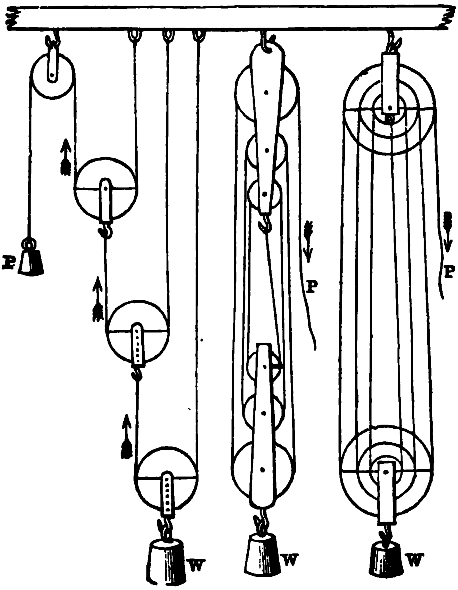


Fig. 177.

developed in relation to the lever. If, for example, in the system of pulleys on the left, the weight be 36 pounds, the two cords of the first pulley will each sustain a weight of 18 pounds, those of the next pulley each 9 pounds, and those of the next each 4½ pounds. The weight W then will be balanced by the weight P if it weigh 4½ pounds.

241. **Inclined Plane.**—The fourth mechanical power is the Inclined Plane. This being a very simple contrivance is much used, especially when heavy bodies are to be raised only a small height, as in getting large boxes and hogsheads into stores. The mechanical advantage of the inclined plane may be illustrated on Fig. 178. The line A *c* represents an inclined plane. If a weight be drawn up this plane it is raised only the height B *c*. A smaller power is requisite to draw the weight up the plane than to raise it perpendicularly; and the power necessary will be the less the longer the plane. A power which would balance a weight on an inclined plane would be to the weight as the height of the plane to its length. Thus if A *c* be twice as long as B *c*, a weight of four pounds on the plane may be balanced by a two-pound weight suspended by a cord passing from the weight over the summit of the plane. A flight of stairs is an inclined plane in regard to the principle on which the ascent is effected, the projections in it being for the purpose of affording a sure footing in making the ascent or the descent. So likewise hogsheads are let down the steps of a cellar-way by ropes, and it makes no difference in the principle of the operation whether the steps have or have not planks laid along them. It is supposed that the immense stones in the pyramids and other massive Egyptian structures were put into their position by means of the inclined plane. Roads, when they are not level, are inclined

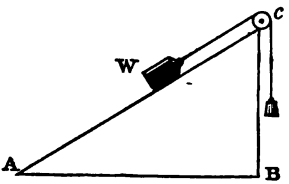


Fig. 178.

planes, and the steeper the inclination the more power is required to draw a load up the road. Great mistakes were formerly made in carrying roads too frequently over high hills. Besides failing to take advantage of the principles of the inclined plane, in many cases the horse in going over a hill passes over quite as much space as he would if the road were made to go round the base of the hill, and sometimes even more. If the hill were a perfect hemisphere, a road over it would be just equal in length to a road around its base to the opposite point.

242. **The Wedge.**—This is the fifth of the mechanical powers. It may be considered as two inclined planes placed with their bases together, as seen in Fig. 179. Indeed, sometimes the wedge has one side only inclined, it being only half of the ordinary wedge. The difference between the inclined plane and the wedge in operation is, that in the first the inclined plane is fixed, and the weight is made to move up along its surface, while in the latter the weight, that is, the resistance, is stationary, and the surface of the plane is made to move along upon it. The power of the wedge is estimated just as the power of the inclined plane is, that is, by comparing the thickness of the wedge with the length of its side. The less the thickness of the wedge compared with its length, obviously the more powerful is the wedge as a penetrating instrument. The wedge is used for splitting blocks of wood and stone, for producing great pressures, for raising heavy bodies, etc. All cutting and piercing instruments, knives, razors, axes, needles, pins, nails, etc., act on the principle of the wedge.

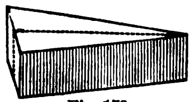


Fig. 179.

243. **The Screw.**—This is the sixth mechanical power. The principle of it is essentially that of the inclined plane. The "thread" running around the screw is an inclined plane which is spiral instead of straight, and so is also

the corresponding part in the nut an inclined plane running in the opposite direction. In the common screw the nut is fixed, and the screw is made to play up and down in it; but sometimes the screw is fixed, and the nut is made to play around it. The screw acts like a wedge, and has the same relation to a straight wedge that a road winding up a hill has to a straight road of the same length and rise. Especially does the comparison hold when the screw is forced into wood; the wedge goes straight into the wood, but the edge of the screw's thread enters the wood spirally.

To estimate the force of the screw we compare the length of one turn of the thread around it with the height to which the thread rises in going round. Let *a b*, Fig. 180, represent one turn of the thread, and *b c* the height to which it goes. It is clear from the figure that the principle which applies to the inclined plane and to the wedge applies here also. As the less is the height of the plane the easier it is for a weight to be drawn up it; and as the less is the depth of the wedge the less is it resisted; so, also, the less the height of the turn of the screw's thread the easier is it to move the screw, and the greater is the force which it exerts. Hence the prodigious power of a screw with a thread which rises very slowly in its spiral turns. Screws are much used when great pressure is required, as in pressing oils and juices from vegetable substances, in compressing cotton into bales, in bringing together with firm grasp the jaws of the vice, etc. In turning the screw a bar is used, so that we have in this instrument the combined advantages of the screw and the lever. That you may have some idea of the power of these two instruments acting together I will suppose a case. Let the weight to be

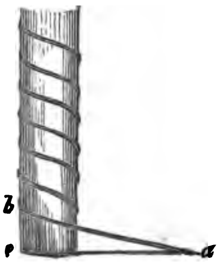


Fig. 180.

raised by a screw be 10,000 pounds. Let a turn of the screw be 10 inches long, and the rise be but one inch. Then, so far as the screw is concerned, the power requisite to raise the 10,000 pounds will be 1000—the ratio of the height of the thread's turn to its length. But the power of the lever is yet to be estimated. Let the length of the lever, passed through the head of the screw so that it is equal on each side, be 30 inches. The diameter of the screw is about three inches, or one-tenth of the diameter of the circle described by the end of the lever. It will now take but a power of 100 pounds to raise the weight, the ratio of the radius of the screw to half the length of the lever.

244. **Truly but Three Mechanical Powers.**—The Wheel and Axle, you have seen, is merely a modification of the Lever, and the Wedge and the Screw are modifications of the Inclined Plane. The Mechanical Powers are, then, in reality but three—the Lever, Pulley, and Inclined Plane. And these are the elements of all machinery, from the simplest tool that is used for the most common purposes to the most complicated and powerful engine which the ingenuity of man ever designed. The principle upon which a pin is shaped is identical with that of the wedge, by which large masses are cleft in two; and the instrument by which the finest textures are cut by delicate fingers is arranged on the same principle with those varied contrivances by which immense weights are raised by a comparatively small power, viz., the principle of the lever.

245. **Friction in Machinery.**—You have seen, as we have proceeded, that the Mechanical Powers, though thus named, do not generate power. So far from this, there is really a loss of power in their use, chiefly from friction. In raising a weight, for example, directly by the hand, there is no loss from this cause; but if you use a pulley you have the friction of the cord upon it, and a loss of power in proportion to the amount of friction.

In some cases the loss of power from this cause is so great as to call for a considerable variation from such calculations as we have made in this chapter in regard to the relations of power and weight in machinery. In the operations of the screw friction has a great influence in diminishing the power of the instrument.

246. **The Real Advantages of the Mechanical Powers.** —If there is then no saving, but a loss of power in tools and machinery, what, let us inquire, are their advantages?

If one man can do alone by the aid of some instrument what would otherwise require the exertion of many men, though he be slow in doing it, yet it is a great advantage. Thus one man can with a lever move a stone which perhaps it would require thirty men to move without it, and though it take him thirty times as long, it saves him the trouble of getting a company of men to help him. So if a man can raise his goods by a wheel and axle to the upper loft of his store, though he raise them slower than several men would lift them directly by ropes, it is an advantage to him, as it saves the hiring of a company of laborers. A few men by a capstan can raise an anchor which could be raised without it only by a large company of men.

Another advantage often is that there may be intervals of rest in applying the force without any loss. This is obvious in the case of the pulley, but still more so in the case of the screw. It is friction in both these cases which enables the workman to rest. It saves to him all that he has gained by opposing any tendency to slip back. We see the same thing in the wedge. When this is driven into wood, it remains because it is prevented from returning by the friction of the wood against its sides. It is the same cause which holds a nail in its place, and opposes any effort to draw it out. In driving the wedge the workman can have as long intervals as he pleases between his blows, because friction saves all that is gained. This effect is very well exemplified in the

capstan, Fig. 170. It requires but little exertion of the man who sits there to hold the rope, because the few turns of it around the axle prevent its slipping easily.

A third advantage which often attends the use of tools and machines is that force may be made to produce motion at various distances, in various directions, and in various degrees of velocity. Thus as to distance, a man standing on the ground can raise a weight to the top of a house by a pulley. So, also, a water-wheel may by the connections of machinery produce motion at considerable distances from it. Then as to direction, horizontal motion may be converted into vertical, rotary into straight, etc. The velocity of motion is generally varied by cog-wheels. Thus a wheel of 60 cogs revolving once in a minute, playing on a wheel of 10 cogs, will make it revolve once in 6 seconds.

Another advantage of tools and machines is that they secure a better mode of applying power than we otherwise could have. Thus when several men are pulling on a rope much power is lost by their pulling irregularly, a difficulty which is removed by the pulley. The same can be said of applying pressure by the screw. One man presses more steadily, and therefore more effectually, than fifty men would without the screw. The arrangements of tools and machines are so made as to provide convenient ways of applying our strength. An instrument, for example, for moving a weight by hand is so shaped as to hold the weight well, and also to afford a good handle for the hand to grasp. The common claw hammer is a very good illustration. We grasp the nail by an iron claw, with the handle we can apply not merely the force of the hand, but that of the whole arm, and then we have the immense lever power of the instrument. We have a good illustration of convenience in an instrument, in what is called a Lewis, represented in Fig. 181. It is used for raising

Fig. 181.

blocks of stone in building. It has three parts, A B C. It is used in this way: A hole is made in the upper part of the block of stone to be raised in shape like the instrument; then A and C are inserted, and B is pushed in between them. With the ring, D, bolted through the instrument the stone is raised to its place by the ordinary machinery. The principle of the instrument, you see, is that of the wedge.

247. **Man a Tool-Making Animal.**—Though there is no actual saving of power in the tools and machines which man uses, yet so great are the advantages which he reaps from them, that more than two thousand years ago a philosopher thought that man could not be better distinguished from brutes than by calling him a tool-making animal. If the distinction was so striking in the time of Aristotle, when tools and machines were so few in number and so rudely contrived, and so few of the sources of power were appropriated by man to his use, how much more striking is it now, with all the variety and perfection of instruments and machinery, and with the ever-extending appropriation of the sources of power furnished by the elements. The power which air and water and gravitation give is applied constantly with more and more variety and effect; and the appropriation of that mighty source of power, steam, is wholly a modern invention.

CHAPTER XII.

SOUND.

248. **What Sound is.**—Sound is such a vibration of substances as can, on being transmitted to the ear, act upon the sense of hearing. I say *such* a vibration, because there may be vibrations which will not produce the sensation of sound. Vibrations which are either

very slow or very quick will not do it. Thus if a plate of metal or a string make less than 15 or more than 48,000 vibrations in a second, no effect is produced upon the ear. The capacity of hearing differs, however, in different persons, so that although few can hear vibrations which are beyond the range which I have mentioned, there are many whose capacity falls much within it either at one end or both ends of the scale. The range for animals is not the same as that for man. Thus the lion and the elephant can hear a sound when the vibrations are too infrequent to make any impression upon our ears; while small animals have a susceptibility in the organ of hearing for vibrations so quick that we can not hear them, and at the same time are not susceptible to the slower vibrations. How far the range varies in different animals has not been ascertained to any extent.

249. **The Vibration of Sounding Bodies Manifest to the Senses.**—If we place the hand upon a large bell that has been struck we can feel the vibration. If we strike one of the ends of a tuning-fork upon some hard body we can see the vibration, as represented in Fig. 182 by the dotted lines. If we look in upon the strings of a piano as it is played, the vibration of the larger strings is very observable to the eye. If we rub the edge of a drinking-glass so as to produce a musical sound, the water which is in it will be thrown into waves from the vibration of the glass.

Fig. 182.

250. **Wind Instruments.**—In wind instruments, as the flute, horn, etc., it is the vibration of the body of air in the instrument which causes the sound. In the common tin whistle or bird-call, Fig. 183, the sound is produced by the vibration imparted to the contained air by the impulse of the breath through the orifice, B.

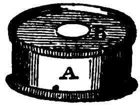


Fig. 183.

251. **An Analogy.**—The vibration of a

sounding body is much like that of a pendulum. The end of the tuning-fork, Fig. 182, on being struck passes to *b*, and in returning passes by the point of rest, A, as the pendulum does, and reaches *a*. So, also, if a string, A B, Fig. 184, be drawn aside to D, as it flies back to C it will by its inertia pass on to E, and so will continue to vibrate back and forth for some time. The same rule also applies to the extent of the vibrations here as in the case of the pendulum, § 209. The quickness of the vibration is not at all affected by its width. The farther the string, A B, is drawn to one side the greater will be the force with which it will return, and hence it will arrive at its position on the other side of the middle line as soon when drawn far away from this line as it would if drawn but little away. The same thing is true of the vibrations or waves of air, though it can not so easily be made plain to you.

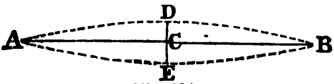


Fig. 184.

252. **How the Sensation of Sound is Produced.**—The vibration of a sounding body is transmitted to the ear ordinarily through the air, and there strikes upon a little drum, a membrane at the bottom of the external cavity of the ear just like a common drum-head. Here the vibration of the air is communicated to this drum, and from this to a chain of very small bones. From the last of these bones it is transmitted to another very small drum, and from this to a fluid in some very complicated passages in the most solid bone in the body. These may be called the *halls of audience*. In the fluid contained in them are spread out the branches of the nerve of hearing, which receive the impression of the vibration, and transmit it to the brain, where the mind takes knowledge of it. Observe that the vibration, transmitted first through the air, then through the drum, then the chain of bones, then another drum to a fluid, stops at the fluid. What is transmitted from this to the brain by

the nerve we know not, and so we call it an impression.

253. **Sound Transmitted through Various Substances.**—In ordinary hearing sound, as you have seen, is transmitted through various substances before the vibration arrives at the liquid in the halls of audience. But sound need not take this course in all cases to arrive at the nerve of hearing. If, for example, you place a watch between your teeth, the sound will go through the solid teeth and the bones of the jaw directly to the halls of audience by a short cut, instead of going round through the outer ear-passage to the drum, and so through the chain of bones. Fishes in hearing receive the vibration through water. If you place your ear at the end of a timber, while some one scratches with a pin at the other end, you hear the sound distinctly, for the vibration is transmitted through the timber; as in the case of the watch between the teeth, it goes through the solid bone.

254. **Sound not Transmitted through a Vacuum.**—As sound is a vibration of some substance it can not be transmitted through absolute space. This can be proved by an experiment with the air-pump, as represented in Fig. 185. The apparatus in the receiver is so arranged that the bell, *a*, can be struck by pressing down a sliding rod, *h*. If it be struck before the air is exhausted the sound is heard through the glass. But the more you exhaust the air the fainter will be the sound; and at length, if you keep on pumping, it can not be heard at all. The same experiment can be tried with a music-box. It is from the thinness of the air on high mountains, and at the great heights reached by balloons, that all sounds are so faint. The report of a pistol fired off on top of Mont Blanc is a mere crack

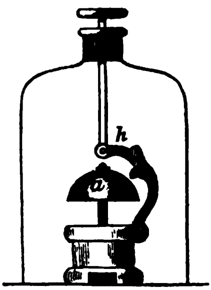


Fig. 185.

compared with its report when fired in the valley below.

255. **Motion of the Heavenly Bodies without Noise.**—Sound is often heard at a very great distance on the earth. The sound of an eruption of a volcano has been heard in one case at the distance of 970 miles. But suppose that the same sound should occur at the same distance from the earth, that is, over 900 miles beyond the atmosphere that enrobes the earth, no inhabitant of our world could hear it, for the same reason that you do not hear the bell ringing in an exhausted receiver. If, therefore, any sound, however loud, should be given forth by any of the heavenly bodies we could not hear it. The course of these bodies in their orbits is noiseless, because they meet with no resistance from any substance. Bodies passing rapidly through our atmosphere cause sound, from the resistance which the air gives to their passage. The whizzing of a ball is an example of this. It is the passage of the electric fluid through the air which produces the thunder. But the heavenly bodies, having no such resistance, make no sound in their course, though their velocity be so immense. In the expressive language of the Bible, "their voice is not heard."

256. **Velocity of Sound.**—The velocity of sound varies in different media. Thus it passes through water four times as rapidly as it does through air. Dr. Franklin, with his head under water, heard distinctly the sound of two stones struck together in the water at the distance of more than half a mile. Sound passes through solids much more easily, and therefore more rapidly, than through liquids. Thus its velocity through copper is twelve times and through glass seventeen times greater than through air. If you place your ear against a long brick wall at one end, and let some one strike upon the other end, you will hear two reports, the first through the wall and the second through the air. Indians are in the habit of ascertaining the approach of their enemies

by putting the ear to the ground. When the eruption of a volcano is heard at a great distance the sound comes through the solid earth rather than through the air. The ready transmission of sound through solids furnishes us with a very valuable means of examining diseases of the lungs and heart. The sounds occasioned by the movement of the air in the lungs and by the action of the heart are very distinctly heard through the solid walls of the chest.

257. **Measurement of Distances by Sound.**—It makes no difference with the velocity of sound whether it be loud or not. Thus the sounds of a band of music at a distance all reach your ear at the same time, the sounds of the instruments that can scarcely be heard keeping exact pace in the air with the sounds of the loudest. So, also, the velocity of sound is uniform throughout its whole course, being just as rapid when it is about to die away as it was when it began. It is from this uniformity in the velocity of sound that we can estimate the distance of the object by which any sound is made. We do it by a comparison between light and sound. Sound moves at the rate of 1120 feet in a second. Now light moves 192,000 miles a second, and therefore, for all ordinary distances on the earth, we need make no allowance of time for light in comparison with sound. If we see, then, the operation by which a sound is produced we can estimate its distance from us by the length of time which elapses between what we see and what we hear. In this way we can estimate very accurately the distance of a cannon that we see fired, or the distance of a flash of lightning.

258. **Loudness of Sound.**—The loudness of sound depends upon the width of the vibrations producing it. The harder you strike the end of the tuning-fork, Fig. 182, the farther will it vibrate the one way and the other, and the louder will be the sound. The same thing is true of the strings of a piano. A round bell, when it is

struck, tends in its vibration to take an oval form, and the extent of its vibration back and forth as it does this governs the loudness of the sound. As sound passes from the sounding body the vibration gradually lessens, and at length dies away. It is like the successive vibrations or waves of water produced by dropping a stone in it. The louder the sound is the larger are the first vibrations, and the farther will the vibrations extend, as in water a large stone dropped into it will produce larger waves than a small one, and the waves will extend over a greater space.

259. **Diffusion of Sound.**—When there is no hindrance sound spreads equally in all directions. It is in this respect with the vibrations or waves of air as it is with the waves of water when a stone is dropped into it. Light is also diffused in the same manner, as you will see in another chapter.

260. **Reflection of Sound.**—As waves of water striking against any object bound off, so it is with the vibrations or waves of sound. And the same is true of this as of all motion, as stated in § 206, that the angle of incidence is equal to the angle of reflection. The reflection of sound is the cause of *echoes*. In order that an echo be perfect the sound must be reflected back to the ear from some plane surface of some size. Sometimes when there are successive plane surfaces of rocks along a river there are successive echoes. Thus in Fig. 186 (p. 200) is represented a locality on the Rhine where a sound is reflected at successive places, 1, 2, 3, 4. The rolling of thunder, though sometimes caused by the different distances of parts of the same flash of lightning, is commonly owing to reflections of the sound among the clouds. From this cause the report of a cannon is more apt to be a rolling sound when there are clouds above than when the sky is clear. Sound is continually reflected in every variety of direction from obstacles with which it meets. Thus in a room it is reflected from the walls and from all the objects in

Fig. 186.

the room; and the more varied are the surfaces the more varied and confused are the reflections. You know that a voice has a very different sound in a room when it is empty from what it has when the room is filled with an audience. Indeed, a blind speaker can estimate very nearly the size of his audience by the sound of his own voice. The explanation is, that with a full audience the surfaces for reflection are vastly multiplied, and so deprive the sound of the sharp and ringing character which is given to it by reflection from comparatively few surfaces which are plane and firm. The effect produced by an audience upon the voice of the speaker is quite analogous to that of muffling upon the sound of a drum.

261. **Whispering Galleries.**—The reflection of sound from curved surfaces gives us some interesting phenomena. The waves of sound in being reflected from a concave surface are gathered together to some point. If the surface be a perfectly spherical one, and the sound issue from the centre, the reflection will be from all points to the centre. But suppose the concave surface have the curve of an ellipse, as represented in Fig. 187. This, instead of having a

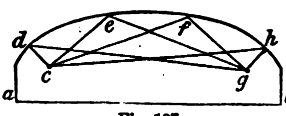


Fig. 187.

centre, has two foci, *c* and *g*. Now if a sound proceed from one focus, *c*, the waves of sound, as represented by the lines *c d*, *c e*, *c f*, *c h*, will all be reflected to the other focus, *g*; so that if a person speak in a very low tone or even whisper at *c*, he may be heard distinctly by another at *g*, though persons at other points may hear nothing. We may have this result with a curved wall extending even several hundred feet; and such structures are called whispering galleries. If in one of these galleries a person standing in one focus speak loudly he will be heard by others at any point by the *direct* waves of sound; but the reflected sound will be added to the direct in the case of one standing at the other focus.

262. **Concentration of Sound.**—It is by the reflection of sound that it can be concentrated in various ways. Thus in using a speaking-trumpet the waves of sound, instead of moving in all directions as soon as they escape from the mouth, are reflected by the sides of the instrument toward a central line, as represented in Fig. 188. The waves or vibrations, being thus concentrated, have more intensity and are thrown to a greater distance than if they issued directly from the mouth. So a speaking-tube, confining the vibrations, carries the voice to distant parts of a building. For the same reason the voice can be heard much farther through a narrow street than in an open space. So, also, a speaker can be heard more distinctly in a hall than when addressing an audience of the same size in the open air. The "sounding-board," once so fashionable in churches, was really of considerable service in preventing the escape of the vibrations of the voice of the preacher upward, and directing them downward upon the audience. In the

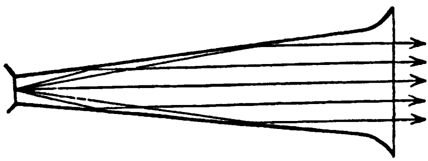


Fig. 188.

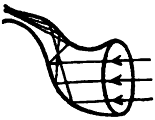


Fig. 189.

hearing-trumpet, Fig. 189, the vibrations are collected in the broad open end of the instrument, and by reflection are thrown together into a narrow compass before they enter the ear to strike upon the drum. We often instinctively make the palm of the hand act as an ear-trumpet when we do not hear distinctly. Many animals have the external ears movable, so that they can direct their concave surface toward the point from which they wish to hear. Such ears are movable ear-trumpets.

263. **Difference Between a Musical Sound and a Noise.**—The difference between a musical sound and a noise is very analogous to the difference between a crystal and the same substance destitute of the crystalline arrangement. In both there are vibrations, but in the musical sound they have perfect regularity, while in a noise the vibrations are irregular, and there is confusion. Indeed so regular are the vibrations of musical sounds that the rules and principles of music have all the rigid exactness of mathematics.

264. **How Different Notes are Produced.**—The quicker is the vibration the higher is the note. Thus a short and small string on a violin or in a piano gives a higher note than a long and large string, because its vibrations are quicker. The tension of the string also has an influence, the note being raised by increasing the tension. In tuning a violin the right pitch is given to each string by lessening or increasing the tension by means of the screws to which the strings are attached. In playing upon it various notes are made upon each string by shortening the vibrating portion more or less by pressure of the finger.

In wind instruments the note depends on the length and size of the column of air contained in them. This may be illustrated by an organ-pipe, Fig. 190 (p. 203). It is one of the pipes of what is called the flute-stop. It

Fig. 190.

is constructed very much like a boy's willow whistle. The air from the bellows of the organ enters at P, and causes a vibration of the whole column of air in the pipe, the sound issuing at *t*. In the upper end is a movable plug, *s*, by which, in tuning, the note of the pipe is regulated. If the note be too grave this plug is pushed downward, so as to shorten the column of air.

It is from difference in rapidity of vibration that a large bell gives a graver note than a small one. So, too, when musical sounds are produced by passing the moistened fingers over the edges of glass vessels, the larger the vessel the graver is its note. A tumbler will give a graver note than a wine-glass.

265. **Human Voice.**—The principles which I have developed in relation to musical instruments apply to the voice. The musical instrument of man, by which the voice is produced, is contained in a very small compass. It is that box at the top of the throat commonly called Adam's apple. Across this, from front to rear, stretch two sheets of membrane, leaving a space between their edges. In our ordinary breathing these membranes are relaxed, and the space between their edges is considerable, to allow the air to pass in and out freely. But when we speak or sing these membranes, or vocal chords, as they are termed, are put into a tense state by muscles pulling upon them, and the opening between them is lessened. The voice is produced by the air that is forced out from the lungs, which, striking on the chords, causes them to vibrate. The nearer their edges are together, and the more tense they are, the higher is the note. The sounds are produced precisely as those of the Æolian harp are, the air causing in the one case a vibration of strings, and in the other of edges of membranes.

266. **Harmony.**—When notes, on being sounded at the

same time, are agreeable to the ear, they are said to harmonize. Now this harmony depends on a certain relation between the vibrations. The more simple is the relation the greater is the harmony. For example, if we take the first note, termed the fundamental note, of what is called the scale in music, it harmonizes better with the octave than with any other of the eight notes, because for every vibration in it there are just two in the octave. Take in contrast with the octave the second note. Here to every eight vibrations of the first note we have nine of the second, and the consequence is a discord when they are sounded together. The difference between the two cases is this: In the first case the commencement of every vibration in the fundamental note coincides with the commencement of every second vibration in the octave. But in the other case there is a coincidence at only every eighth vibration of the first note with every ninth of the second. Next to the octave, the most agreeable harmony with the fundamental note is that of the fifth note of the scale. Here we have three vibrations to every two of the first note, and so every second vibration in the first note coincides with every third vibration of the fifth. Next comes the harmony of the fourth, there being here a coincidence at every third vibration of the fundamental note. The more frequent, you see, are the coincidences between the vibrations the greater is the harmony. In the three cases just stated the coincidence is in the first at the commencement of *every* vibration of the fundamental note, in the second case at the commencement of every *second* vibration, and in the third at the commencement of every *third* vibration.

267. **The Diatonic Scale.**—In order that you may see the relative numbers of the vibrations for each of the notes I will give them for the whole scale. They are as follows:

1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
C	D	E	F	G	A	B	C.

According to this the note D has nine vibrations to every eight vibrations of C, E has five to every four of C, etc., the octave C having just twice the number of vibrations that the fundamental note C has. You have here expressed the *proportion* between the numbers of vibrations in the different notes. Suppose, then, that you know the number of vibrations in a second that C, the fundamental note, has, you can readily calculate the number of vibrations of each of the other notes. It is done by multiplying the number which C has by the fractions over the other notes. Thus if the number of vibrations in a second in the fundamental note be 128, by this process we make the vibrations of all the notes to be thus:

C	D	E	F	G	A	B	C
128	144	160	170	192	213	240	256.

There are really but seven notes in what is called the diatonic scale, the eighth note, C, being truly the first of seven other notes above, having relations to each other similar to those of the notes below, and constituting another octave. So we may have several octaves, one above another.

It is interesting to observe that the proportionate lengths of strings required to produce the eight notes of the scale have an exact numerical relation, but the *reverse* of that of the numbers of the vibrations. Thus if you have eight strings of the same size, their vibrating lengths required for the notes are as follows:

C	D	E	F	G	A	B	C
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$.

For the notes of the octave above the lengths are thus:

C	D	E	F	G	A	B	C
$\frac{1}{2}$	$\frac{4}{9}$	$\frac{2}{5}$	$\frac{3}{8}$	$\frac{1}{3}$	$\frac{3}{10}$	$\frac{4}{15}$	$\frac{1}{4}$.

268. **Unison.**—In tuning instruments so as to make them harmonize the result is obtained when the corresponding parts of the instruments have the same number of vibrations. Thus the string in one violin that gives any particular note must vibrate just the same number

of times in a second that the strings giving the same note in other violins do, or it will not be in perfect unison with them. The same is true of other strings for other notes, and also of the corresponding parts of all kinds of instruments which are to be played together. When, in tuning instruments together, it is said that a string of a violin, for example, is too *flat*, the difficulty is that it does not vibrate with sufficient rapidity, and it is therefore screwed up to make its note *sharp* enough, as it is expressed, to be in unison with the note of the corresponding strings or parts of other instruments.

269. **Mysteries of Sound and Hearing.**—There are many things of a mysterious character in relation both to sound and the manner in which it causes the sensation of hearing. I will barely notice but two of these. The effect, or rather the chain of effects, resulting in hearing is wholly mechanical, until we come to the nerve of hearing, which branches out with minute fibrils in the halls of audience of the internal ear. It is merely a series of vibrations. Now how it is that the mere agitation of a fluid inclosed in hard bone can communicate through fine white fibres to the brain, and through that to the mind, the idea that we have of all the various sounds that are produced, is a great mystery. All that we know is that the nerve is the medium of the communication, but of the manner in which it performs its office we know absolutely nothing. Again, while it is sufficiently mysterious that this information can thus be given to the mind when one sound after another communicates its vibration to the liquid in the ear, the mystery is greatly enhanced when various sounds come to the ear at one and the same time. To get a distinct idea of the very compound and wonderful character of the process of hearing in such a case we will suppose that a full band of music is playing, and at the same time mingled with its sounds there are various other sounds heard, some of them perhaps discordant. What a diversity of vibra-

tions we have here! We have the slow vibrations produced in the grave notes, and the quick vibrations of the higher ones, all traveling together through the air to the ear, and each preserving its distinctive character. And more than this, after they arrive at the ear they are communicated unaltered through the drum, the chain of bones, the second drum, and the liquid where the nerve is, so that a correct report of each of all the notes is given through the nerve to the mind. Then, too, if there be any discord its vibration travels along with the rest, and so do the vibrations of other sounds, as the roaring of the wind, the report of cannon, and the noise of the people. And besides all this, in the multiplicity of the vibrations thus transmitted through so many different substances the mind gets a true report of the comparative loudness of the sounds, and even of their character, so that the sounds of drum, fife, trumpet, etc., are all accurately distinguished. In view of such wonders how significant is the question, "He that planted the ear, shall he not hear?"

CHAPTER XIII.

HEAT.

270. **Heat and Cold.**—In common language we speak of heat and cold as two distinct and opposite things. That this is not strictly correct may be shown by the following experiment: Take three vessels, and fill the first with ice-cold water, the second with hot water, and the third with tepid water. If you place your right hand in the first and the left in the second, and let them remain a little time, on taking them out and plunging them together into the third vessel, the water in it will feel warm to the right hand and cold to the left. So the air of a cellar seems warm to you in winter and cold in

summer in contrast with the air outside. For the same reason water of a temperature that would ordinarily be refreshingly cool to us seems warm when drank after eating ice-cream. It is manifest, then, that there is no fixed dividing-line between heat and cold. There is, in fact, no such thing as cold. Substances are cold from being deprived of heat; and no substance ever has all its heat taken from it. Sir Humphrey Davy proved that there is heat in ice by rubbing two pieces together in a very cold room. They were gradually melted. Now this was not done by the air, for that was at a temperature below the freezing point. The heat which melted the ice came from the ice itself by means of the rubbing.

271. **Nature of Heat.**—There are two theories in regard to the nature of heat. One is that heat is an imponderable (§ 16), and of course a very subtile substance, which pervades all matter. Its particles are supposed to repel each other strongly, and hence they have a tendency to diffuse themselves, and to separate the particles of matter from each other. It is in this way that they are supposed to occasion the expansion of substances. The other supposition, which is most commonly received, is that heat is a vibration of the particles of bodies, and that it passes from these to bodies less warm through a subtile fluid called ether, supposed to fill all space. You see that if this be the true theory, there is some analogy between heat and sound.

272. **Sources of Heat.**—The principal of the sources of heat on our earth is the *sun*, though that body is ninety-five millions of miles distant from us. As the heat, in traveling all this long journey, is becoming more and more diffused; or, in other words, as its rays are all the way separating from each other more and more, we can have no conception of the concentrated heat that exists in the sun itself. We can, however, approximate to the idea by observing the effects of heat when some of its separated rays are gathered to a point by a powerful

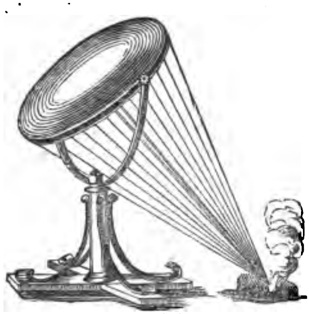


Fig. 191.

lens, as represented in Fig. 191. A lens which concentrated the heat ten thousand times melted platinum, gold, quartz, etc., in a few seconds. And as the heat at the sun is supposed to be thirty times more concentrated than this, none of the most solid substances of our earth would remain solid if they were there, but would be some of them liquid, and others even in a state of vapor. The heat which the sun constantly radiates to the earth pervades all substances, producing motion, and awakening life every where, so that, in the expressive language of the Bible, "There is nothing hid from the heat thereof."

Another source of heat is *within the earth itself.* It has been found as we go down into the earth there is a constant increase of temperature the farther we go. This internal heat is attributed in part to subterranean fires and various chemical actions. We see here and there external evidences of the operation of these causes in the eruptions of volcanoes, the boiling springs, the jets of steam and sulphureous vapors, etc. But that the heat in our earth which comes from these subterranean sources is small compared with that which comes from the sun, is seen in the fact that the rate of increase of heat at great depths is much less than it is nearer the surface. This would seem to show that although fires within the earth may have considerable influence in heating its crust, on which we live, it derives the most of its heat from the sun, at least to a very great depth.

How great a source of heat *electricity* is we know not, but that considerable heat comes from this source is evident from the melting and burning effect which

we often see resulting from the passage of the electric fluid.

Another very common source of heat is *chemical action.* We see it continually produced in chemical experiments. Combustion, which, as will be shown to you in the Second Part of this Series, is nothing but an example of chemical action, is the most common of all the chemical sources of heat. Animal heat is also, for the most part, a result of chemical action.

Mechanical action is a common source of heat. The rubbing of a match producing heat enough to occasion flame is a familiar example. The spark produced in what is called striking fire is the burning of a particle of steel set on fire by the blow. The Indian was accustomed to light his fire by the rubbing together of two dry sticks till he learned an easier way from civilized neighbors; and the blacksmith, previous to the invention of phosphorus matches, often lighted his fire by touching a sulphur match to a nail made red-hot by rapid and continued hammering. Machinery has sometimes been set on fire by friction, and the water around a mass of metal has been so heated by boring as even to boil. If you stretch a piece of India rubber several times in quick succession, and then apply it to your lips, you will perceive that the motion has warmed it.

273. **Relations of Heat and Light.**—Heat is sometimes alone, and is sometimes in intimate union with light. All substances have some amount of heat, and it passes from them to other bodies in their neighborhood that happen to have less heat in them. In doing this it may or may not have the company of light. In the radiation of heat from a stove, unless it be heated to redness, there is no light with the heat; but from an open, burning fire the light and heat come together. But the rays of the sun give us the best example of the union of light and heat. Traveling together at an equal pace they are most curiously mingled, as you will see when I come to speak particularly of light.

I will now proceed to notice the principal effects of heat; viz., expansion, liquefaction, and vaporization.

274. **Expansion in Solids.**—Heat, you have seen in § 23, acts in opposition to the attraction of cohesion, tending to separate the particles, and so produces an expansion of any substance. This may be exemplified in the experiment represented in Fig. 192, in which A B is an iron rod, which is of such a size that at the ordinary temperature it will fit into the space, C D, in a bar of iron, and easily pass through the hole, E. If the rod be heated it will be enlarged or expanded in all directions, so that it will neither fit into C D nor pass into the hole, E. When the wheelwright puts a tire upon a wheel he uses the expansion of heat to make it fit tightly and firmly. The tire is made a little too small to have it fit upon the wheel as it is. But by being heated it is so expanded that it will readily go on to the wheel, and then in contracting as it cools it so compresses the fellies as to hold on very tightly. Water is poured on to cool the iron quickly, and thus prevent it from burning the wood. Iron hoops are put on barrels in a similar manner, the compression caused by their contraction binding the staves together very strongly. So in fastening the plates of boilers together, the rivets are put in red-hot, so that in their contraction they may press the plates closely together. If an iron gate just shuts into its place in cold weather, its expansion will prevent its shutting when warm weather comes. In order to avoid this difficulty, calculation must be made in fitting it for its place for the expansion to which it will be subjected by heat. So in laying the rails of a railroad in cold weather care must be taken not to put the ends

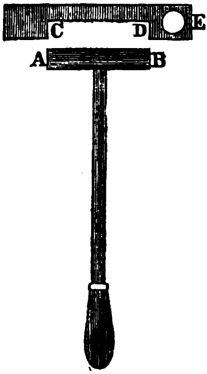


Fig. 192.

too near together. In constructing iron bridges the expansion by heat must be calculated for in the arrangement. Nails often become loose after the lapse of years from the wear of the wood around them, occasioned by their alternate expansion and contraction. The leaking of gas-pipes in the earth is often undoubtedly caused by the loosening of the joints from contraction and expansion of the pipes by varying temperatures of the soil, especially where they are not laid very deep. If a stopper stick fast in a bottle it can be loosened by the application around the neck of a cloth dipped in hot water, because the neck becomes expanded at once by the heat. A similar expedient was once very ingeniously made use of in repairing the machinery of the steamer *Persia* at sea, and was perhaps the means of saving the vessel and the lives of all on board. The accident which occurred was the breaking of the port crank-pin of the engine. The problem to be solved was the removal of this pin, which weighed nearly a ton, and the substitution of a sound one which they had on hand in its place. But it was found impossible to start the broken pin from its socket with all the force which could be brought to bear upon it, by a sort of battering-ram constructed extemporaneously for the purpose. It was determined now to try the expansive force of heat. An iron platform was built under the socket, and a brisk fire made upon it. The socket soon expanded, and the pin was now readily knocked out by the battering-ram, just as the stopper of the bottle is easily removed when the neck is heated. The walls of a very large building in Paris, which had bulged out and were in danger of falling, were restored to their upright position by the expansion of heat. It was done in this way: Long rods of iron were run through the walls after the plan represented in Fig. 193 (p. 213), their ends being made with a screw-thread, with nuts fitted to them. The rods marked *a* were first heated, and as they lengthened the nuts were screwed up

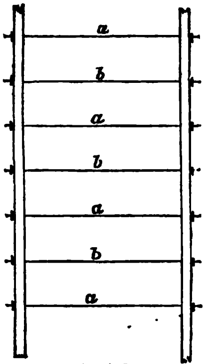


Fig. 193.

tight to the walls. On cooling, their contraction would of course draw the walls together. The other bars, *b*, were now heated and managed in the same way. The one set, you see, were made to hold on by their nuts to what had already been gained, while the other were expanding. By many repetitions of this process the walls were righted and the building saved. The same mode has been adopted successfully in other cases of a similar character.

275. **Expansion in Liquids.**—Liquids are expanded by heat more than solids are. But they are very unequally expanded by it. Thus water is expanded more than twice as much as mercury, and alcohol six times as much. We have a frequent example of the expansion of water by heat in our kitchens. If the tea-kettle be put over the fire filled to the brim, it will run over long before the water begins to boil. All liquids occupy more space in summer than in winter, and in the former case weigh less—that is, have less of real substance in them than in the latter. If, therefore, alcohol, or oil, or molasses be bought by the gallon in winter and sold in summer, there will be a profit afforded by the expansion. Twenty gallons of alcohol in winter becomes twenty-one in mid-summer.

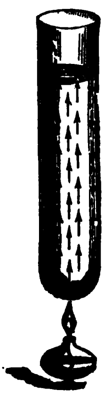


Fig. 194.

The influence of the expansion of heat upon the specific gravity of liquids may be very prettily shown by the following experiment: Let some little bits of amber—a substance which is nearly of the same specific gravity with water—be thrown into water in a glass vessel, and let the water be heated, as represented in Fig. 194, by a spirit-lamp. That portion of

the water which is heated passes upward because it is made specifically lighter, and colder water continually comes down to take its place. The upward and downward currents are as indicated by the arrows, the upward passing up in the middle, the downward coming down at the sides. This will be made manifest by the little bits of amber.

276. **Thermometers.**—It is the expansion of liquids by heat that in the thermometer gives us the measure of temperature. The liquid metal mercury is commonly used for this purpose, and answers well except in the extreme cold of the arctic regions. There, as mercury becomes solid at 39 degrees below zero, it is necessary to use a thermometer with alcohol in it, as this fluid can not be frozen by any degree of cold. The operation of the thermometer is simply this: Heat expands the fluid in the bulb, and the only way in which it can occupy more space as it expands is by rising in the tube. The abstraction of heat, on the other hand, causes contraction, and of course a proportionate falling of the fluid.

277. **Fahrenheit's Thermometer.**—The thermometer was invented in the beginning of the seventeenth century, but it is not decided who was the inventor. There may have been in this case, as in others, more inventors than one, the same ideas having, perhaps, entered several inquiring minds at the same time. Various fluids were used by different persons. Sir Isaac Newton used linseed oil. Fahrenheit, a native of Hamburg, who flourished in the first part of the last century, was the first to use mercury. Though various propositions were made by Newton and others in regard to the measurement of heat by thermometers, no thermometric scale seems to have met with general reception till that of Fahrenheit's, which was put forth about 1720. The plan of it is this: His zero is the point at which the mercury stood in the coldest freezing mixture that he could make; and he supposed that this was the greatest possible degree of

cold, as it was the greatest that he knew. He next found the point at which the mercury stood in melting ice. This he called the freezing point, because the temperature is the same in water passing into the solid from the fluid state as in water passing into the fluid state from the solid. In other words, this point in the scale marks the transition line between the two states. From this point Fahrenheit marked off 32 equal spaces or degrees down to zero. He now found the point at which the mercury stands in boiling water, and called this the boiling point. Marking off the space on the scale between this and the freezing point in the same manner, there are 180 degrees—that is, the boiling point is 212 degrees above zero. The degrees above zero are commonly designated by the mark +, plus; and those below by the mark –, minus. Thus, +32° signifies 32 degrees above zero, and –32° signifies 32 degrees below.

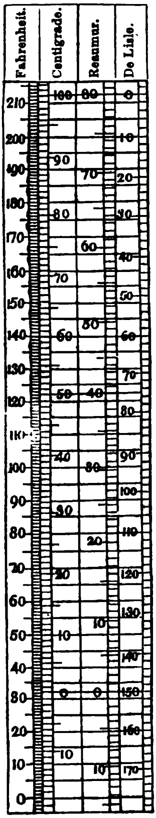


Fig. 195.

278. **Other Thermometers.** — Fahrenheit's thermometer is the one commonly used in this country. But there are several other thermometers on different scales, as the Centigrade, Reaumur's, and De Lisle's. In Fig. 195 you see the plans of the scales of these thermometers placed side by side. In the Centigrade thermometer, which is in use in France, and indeed in a large part of Europe, the zero, you see, is placed at the freezing point; and the space between this and the boiling point is divided into 100 degrees, which gives it the name Centigrade. Reaumur's, which is in use in Russia, has the same zero, but he has only 80 degrees

from this to the boiling point. De Lisle's, which has gone entirely out of use, has its zero at the boiling point. The arrangement of Fahrenheit, although its zero is a mere arbitrary point, is, on the whole, the best, because its degrees are of such a size that they mark differences of temperature with sufficient minuteness for all practical purposes of an ordinary character without resorting to fractional parts.

279. **Expansion in Aeriform Substances.**—Heat produces a vastly greater expansive effect in air, the gases, and vapors, than it does in liquids. The expansion of air by heat may be shown very prettily in this way: Take a glass tube that has a bulb on one end, and, placing the other open end in water (as represented in Fig. 196), apply the palm of your hand to the bulb. The heat of the hand being communicated to the bulb will expand the air, and so, as you see, bubbles of air will escape through the water. On removing the hand, and allowing the bulb to cool, the air in it will be condensed, and water will pass up in the tube in proportion to the amount of air which has escaped.

Fig. 196.

A bladder partly filled with air will be made to swell out to plumpness if it be heated sufficiently, and a full one may be so heated as to burst from the expansion of the air. Porous wood, as chestnut, snaps very much when burned, because the heat expands the air contained in the pores.

280. **Balloons.**—The first balloons that were used were filled with heated air. You have already seen, in § 149,

why it is that balloons rise. Now in the hot-air balloon it is the expansion of the air by heat that makes it lighter than the surrounding air. Of course such a balloon is not as effective as the gas balloon, for the air within it loses its comparative lightness as it becomes cooled; while the gas which is used, being very much lighter than air at the same temperature, does not lose its lightness as the balloon goes up. You learned in § 152 that the atmosphere becomes thinner as we go upward. The gas balloon, therefore, rises until it arrives at that point where the air is of about the same specific gravity with the gas, and there it stops. It is made to descend by letting out some of the gas from a valve. Gas was not used for balloons till 1782. Hydrogen gas was employed at first, being over fourteen times lighter than air. Of late the common burning gas, carbureted hydrogen, has been generally used, because it can be so readily obtained where there are gas-works.

281. **Currents in the Air from Heat.** — Heat is the grand mover of the atmosphere. Any portion of it that becomes warmer than surrounding portions rises, or rather is pushed up, for the same reason that a hot-air balloon rises, the only difference between the two cases being that in the one the air is confined, and in the other is left free, and so becomes diffused. And it is this rising of the air from expansion that causes nearly all the movements that we witness in the air. We see this exemplified in various ways wherever there is a fire. The air that is heated by the fire is forced upward by the colder air, which, on the principles of specific gravity, seeks to get below the warmer and lighter air. The hot air that comes through the registers of a furnace is pushed up by colder air below. For the same reason the heated air around a stove-pipe is constantly going upward. This is very prettily shown by the toy represented in Fig. 197 (p. 218), which is a paper cut spirally, and suspended, as you see, upon the point of a wire. The up-

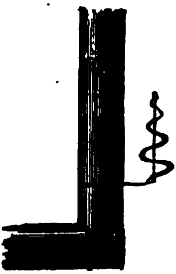


Fig. 197.

ward current makes the paper revolve rapidly around the wire. It is from the rising of warm air that the galleries of a church are warmer than the space below. In a common room the disposition of the air is continually to have its warmest portions above and the colder below. It is for this reason that we have our arrangements for producing or introducing heat at as low a point as possible.

282. **Chimneys.**—We speak of the *draught* of a chimney, and we say of one that does not smoke that it *draws* well, as if the smoke were in some way actually drawn up. But the same principles apply here as are developed in § 281. The smoke, which is a combination of heated air and gases with some solid matters in a fine state, is *forced* up the chimney. When a chimney does not draw well we open a door or a window for a little while until the fire gets thoroughly agoing. Why is this? It is that we may have denser air than there is in the room, so that the smoke may be pushed up more forcibly. When the chimney becomes well heated there is ordinarily no difficulty, because then the smoke in it is not obliged to part with much of its heat to the walls of the chimney, and therefore is so much lighter than the air in the room that it is very easily forced upward. The principal reason that a stove-pipe generally draws better than a chimney is that there is much less heat expended in establishing and maintaining the upward current. Especially is this true if the chimney be a large one. In such a case there are both a great extent of brick and a large body of air to be heated to establish the upward current, and these must be kept warm in order to maintain it.*

* I was once consulted in regard to a smoking stove. It was an open Franklin stove, the pipe of which went through a fire-board

283. **Winds.**—If you open a door of a heated room a candle held near the floor will have its flame blown inward, while one held near the top of the door will have its flame blown toward the cold entry. Here you have a good illustration of the manner in which winds are produced. Wherever the wind blows it is air pushing out of the way other air that is warmer, in order that it may, in obedience to gravitation, get as near the earth as possible. Take, for example, the land and sea breezes, as they are called. During a hot summer's day the sun heats the earth powerfully, while the ocean receives but little of its heat. The heated land heats the air above it; and as the air over the ocean is cooler, and therefore heavier, it pushes upward the air of the land, for the same reason that water pushes up oil; and as this goes on continuously a regular current is established. The wind blows in upon the land, as represented in Fig. 198,

Fig. 198.

into a monstrous chimney. I recommended that a pipe with a knee should extend from the pipe of the stove a little way up the chimney. The expedient was successful, because but a small body of air, that in the pipe, needed to be heated to establish an upward current.

while the warmer air passes upward into the higher regions of the atmosphere, and turns toward the sea. The arrows show the course of the currents. The resemblance of all this to the effect upon the candle held near the open door is very obvious, the cold air from the entry blowing in below representing the breeze from the ocean, and the warm air of the room blowing out above representing the passage of the warm air of the land out toward the ocean. At night this is apt to be reversed. The earth becomes cooled, and with it the air that is over it. The result is that the cooled air of the land now pushes upward the warmer air of the sea, as seen in Fig. 199.

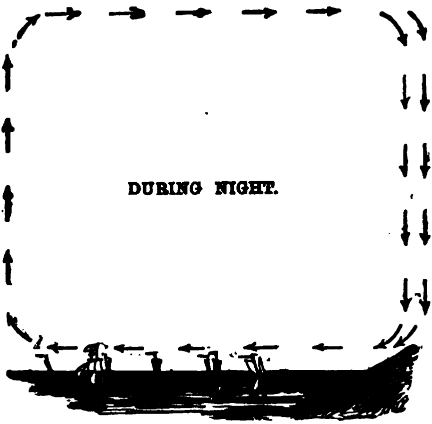


Fig. 199.

284. Winds as Affected by the Rotation of the Earth. —The heat of the vertical sun upon the tropics causes a rise of heated air into the upper regions, while there is a rush of colder air toward the equator from both north and south. This effect is represented in Fig. 200 (p. 221), E being the sun, N the north pole, and S the south pole. An effect similar to that represented in Figs. 198 and 199 is produced here, but it is on a much larger scale.

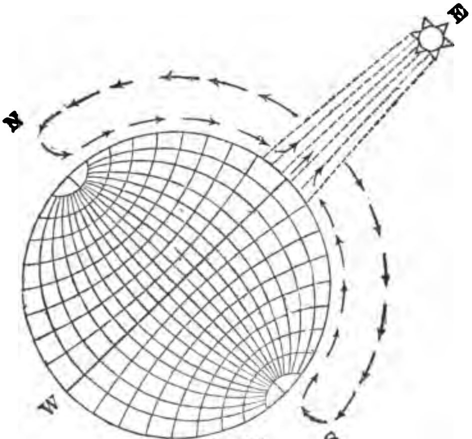


Fig. 200.

But the diagram does not present the matter in its true light in all respects. The prevailing winds in the equatorial regions are not north and south winds, as would appear from this diagram; but they are from the northeast and southeast. I will explain this by Fig. 201. As the earth turns on its axis it is plain that there is no part of the surface of the earth that moves so rapidly as the equator, E W, for that moves in a larger circle than any other part. And the nearer you go to either pole, N or S, the less is the rapidity of the revolution. Now the atmosphere, as stated in § 188, partakes of the motion of the earth. The air, therefore, at the equator is moving from west to east with the rotation of the earth

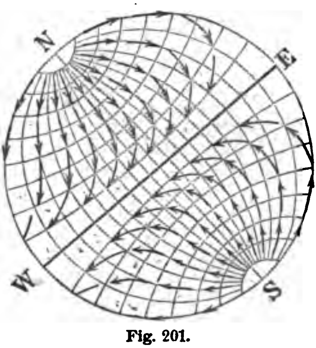


Fig. 201.

faster than it is any where else, and the nearer you go to either pole the slower is its motion. It follows from this that any portion of air blowing from the north or the south toward the equator, as it comes from where it was moving east slower than air at the equator is, would from its lesser momentum lag behind the air of the equator, the wind would be curved toward the westward, as indicated by the arrows. The result would be that the northern wind would be converted into a northeaster, and the southern into a southeaster. All this can be made more clear with a globe, or, indeed, with any round object.

285. **Liquefaction.**—The change of solids into liquids is one of the most observable effects of heat. This change requires different degrees of heat in different substances. Thus while iron melts at the high heat of 2786°, lead melts at 633°, sulphur at 239°, ice at 32°, and mercury at 39° below zero. Mercury is never found in a solid state, but it sometimes becomes solid in the arctic regions when carried there and exposed in the open air. We are apt to think of water as being in a more natural state when liquid than when it is solid, just as we think of iron as being naturally solid and mercury as naturally liquid. But in all these cases the state of the substance depends on its temperature, and this is varied by circumstances. Water at the equator is always liquid, and the idea of ice there is exceedingly unnatural; while near the poles it is the reverse, ice and snow reigning every where throughout the whole year.

286. **Evaporation.**—There are two ways in which the change of a liquid into a vapor occurs. One is a rapid change when heat is so applied as to raise the liquid to its boiling point. This is commonly termed vaporization. The other mode is the ordinary gradual evaporation which goes on from the *surface* of the liquid. This process is going on continuously, not requiring any particular degree of heat, but occurring under all degrees of

the temperature of a liquid. Its rapidity, however, is in proportion to the degree of heat, as may be seen by the rise of vapor from water that is being heated, long before it begins to boil. The same thing can also be seen in a bright summer's morning, when the heat of the sun causes the moisture gathered from rain or dew to rise so abundantly from fences, and boards, and roofs as to be visible like smoke.

287. **Solution of Water in Air.**—Evaporation is constantly going on from every wet surface, except when the air is so loaded with moisture that it can take up no more. The vapor is not ordinarily visible, the particles of water passing quietly upward among those of the air, being dissolved in the air just as some solids are dissolved in water. It becomes visible only when so much of it rises that the solution of the water in the air is not readily effected. The readiness with which the solution takes place depends much upon the temperature of the atmosphere. Some very common phenomena illustrate this. In a very cold day the breath of animals, as it comes out of the mouth, seems to be loaded with moisture. Why? It is not because there is more moisture in it than in warm weather, but because cold air can not hold in solution so much water as warm air can. The same explanation applies to the smoking of wet fences and roofs in the sun of a summer's morning. The moisture is heated by the sun, but the air, not having become very warm as yet, can not readily dissolve all the moisture that rises. The phenomenon is not apt to occur when the hot sun shines after a shower at mid-day or in the afternoon, because then the air is warm enough to take up all the moisture that is sent up into it.

How water, being heavier than air, rises in the atmosphere is a mystery. It has been supposed by some that it was owing to a kind of affinity existing between water and air. But in opposition to this is the fact that evaporation takes place more rapidly under the exhausted

receiver of an air-pump, where there is almost no air, than it does where it is freely exposed to the atmosphere.

288. **Clouds.**—The water which goes up in the air in evaporation is variously disposed of. Some of it is deposited as dew or frost. Some of it forms fog. Some of it also mounts far upward and forms the clouds, which are really collections of fog made high up in the air. In fog and in clouds the water which in its evaporation is invisible becomes visible. Let us see how this is. There is always more or less of water in clear air, but the particles are so minutely divided and so thoroughly mingled with the particles of the air that they can not be seen. But in a fog or cloud the particles of water are gathered together in little companies, as we may express it. And it is supposed, some think ascertained, that each of these companies of particles is globular and hollow. If so, then we may regard every cloud as a vast collection of minute bubbles or balloons careering through the air.

289. **Shapes of Clouds.**—Clouds have a very great variety of shape, the causes of which are for the most part not understood. They are generally divided into four classes: Cirrus, Cumulus, Stratus, and Nimbus. The *Cirrus* is represented in Fig. 202 (p. 225). It is a light, fleecy cloud, having graceful turns like curls, and hence its name, which is the Latin word for curl. Such clouds are commonly very high up in the air. The *Cumulus* (Latin for heap) you see in Fig. 203 (p. 225). Clouds taking this form appear as heaps rounded upward, and often appear like mountains of snow when they are illuminated by the sun. We see such clouds mostly in summer. The *Stratus* (Latin for covering) is seen in the same figure under the Cumulus. Clouds of this form lie low in the horizon, stretched along like a sheet. They often form in the latter part of the day, and increase in the night, but the rising sun dissipates them. The *Nimbus*, or rain-cloud, is represented in Fig. 204 (p. 226). It has a uniform gray or dark color. We often have

Fig. 202.

two forms of cloud mingled together. Thus in Fig. 205 (p. 226) we have a mixture of the Stratus and the Cirrus, termed *Cirro-Stratus*. This is commonly called the mackerel-sky, and is quite a sure prognostic of rain. Then we have the *Cirro-Cumulus*, Fig. 206 (p. 227), and the *Cumulo-Stratus*, Fig. 207 (p. 227).

Water is gathered into clouds undoubtedly, in part at

Fig. 203.

Fig. 204.

least, from the influence of attraction. But what the circumstances are that give them all these various shapes we know not. Whatever they are, they sometimes operate very extensively, giving a similar shape to all the clouds that cover the whole arch of the heavens; and at other times they operate variously in different localities, producing different shapes, sometimes even in near neigh-

Fig. 205.

Fig. 206.

borhood to each other. Sometimes the edge of a cloud is irregular, or curved, or feathery; and at others it is a well-defined line, stretching along over a large portion of the horizon. In all these cases we have only divers arrangements of the same thing—a collection of vesicles of water containing air, which is made lighter than the air outside of the cloud by means which I shall speak of in another part of this chapter.

Fig. 207.

290. **Rain, Snow, and Hail.**—When it rains the vesicles or minute bubbles of which the clouds are composed are broken up, and each drop of rain contains the water which came from a multitude of these vesicles. But let us see exactly how this result is produced. Rain comes from the contraction of the clouds by cold. A cold current of air coming in contact with a cloud will condense its bubbles into drops, and these of course will fall. The same result occurs if a cloud passes into a cold stratum of air. But let us look at the process more minutely. Let us see what the effect of cold is upon the bubbles.

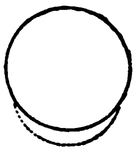


Fig. 208.

The first effect may be made clear by Fig. 208. If a bubble be contracted by the influence of cold, the water of its wall being made thicker, there will be a gathering of it from gravitation at the lower part, as represented by the dotted line. You often see a similar effect in the soap-bubble. It rises filled with the warm air from your lungs, and as it goes up it is contracted by the colder air which is around it. This contraction makes the water hang downward from the bottom of it. And as the soap-bubble at length perhaps bursts in the air from the weight of this water, so it is with the vesicles in the cloud. And many of these, united together by attraction, form a drop. When the cold is sufficiently severe it makes the water of the ruptured vesicles of the cloud arrange itself in snow-crystals instead of drops. And when the cold acts with great rapidity upon a cloud it presses the particles of the water together so suddenly that there is not time for the crystalline arrangement, and hail is formed.

291. **Vaporization.**—The production of vapor by boiling differs in some respects from quiet evaporation. Here the liquid is raised in temperature to its boiling point, and the formation of vapor is not confined to the surface. In water the boiling point is 212°, but it varies more or less from this in other liquids. Thus the boiling point

of alcohol is 173°, of ether 95°, oil of turpentine 568°, and mercury 652°.

292. **Influence of Pressure upon the Formation of Vapor.**—Pressure restrains the production of vapor, whether it be formed by evaporation or vaporization. We know by experiments with the air-pump that the less pressure of air there is upon the surface of a liquid the more rapidly will evaporation from it go on. I have already spoken of the influence of pressure upon the boiling of liquids in § 171. I will give here a few additional illustrations. Ether boils when it is heated to 95°, three degrees below the heat of the blood in our bodies. If we place some of it in a vessel under the receiver of an air-pump, by exhausting the air we can so take off the pressure that the ether will boil at the ordinary temperature of the air in a room. The restraint of pressure upon boiling is very strikingly shown in the *digester*, Fig. 209. This is a strong boiler, *a*, partly filled with water. A thermometer, *d*, is fastened into it so as to indicate the heat of the water. There is also a tube, *c*, extending to near the bottom of the boiler into a small quantity of mercury which is there. Let, now, the boiler be heated till the water boils, the air being left to escape by the stop-cock, *b*. If the stop-cock be shut, and we continue to apply the heat, we can raise the water to a very high temperature without having it boil at all, because of the pressure of the condensed steam upon its surface. An apparatus somewhat after this plan, called *Papin's digester*, has been used sometimes in cooking. The great heat to which water can thus be raised causes it to extract the nutritious matter from bones and cartilages, affording material for soup from what is commonly thrown away. To guard against the danger of explosion a safety-valve is provided, having a weight upon it

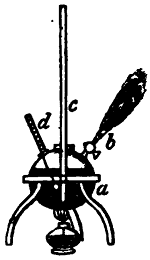


Fig. 209.

which will keep it shut until a certain amount of pressure accumulates, and then it is forced open, letting out some of the steam.

293. **Steam.**—The cloud of steam, so called, which you so often see escaping from a locomotive is not really steam. Steam is transparent and invisible. You can see that it is so if you observe it issuing from the spout of a tea-kettle. It is only after it gets an inch or more from the spout that it becomes visible, and then it is really changed from steam into water by the condensing influence of the cold air. And the water in the cloud thus formed is probably in the same condition with the water in the clouds above, as described in § 288.

294. **The Steam-Engine.**—As compressed or condensed air has great power by its elasticity, as seen in the air-gun, § 164, so also has condensed steam. It is steam condensed, and endeavoring, therefore, in proportion to its condensation, to expand itself, which constitutes the moving force of the steam-engine. The steam is generated in a boiler, having, like the boiler of Papin's digester, a valve with a weight attached to it. This valve is called a safety-valve, because when the steam has reached a certain degree of condensation it lifts the valve, and, as some of the steam escapes, such an increase of pressure as would occasion an explosion is prevented. The expansive force of steam in a boiler is estimated in pounds by the weight on the valve, and hence the common expression that there are so many pounds of steam on. But the boiler is only the generator of steam, and it remains to show how the steam is used in moving machinery. This is done by allowing the steam to pass from the boiler into a cylinder, and then move a piston back and forth by its expansive force. The manner in which it does this may be made clear by the diagram, Fig. 210 (p. 231). Let *e* be a piston in a cylinder, *f*, which has four openings, *a*, *b*, *c*, and *d*. These all have valves. The steam is supplied from the boiler to the

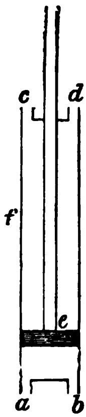


Fig. 210.

cylinder through *a* and *c*, and makes its escape from *b* and *d*. Suppose, now, the piston is near the bottom of the cylinder, as represented. The valve at *a* is now opened that steam may enter to push up the piston, and the valve at *b* shuts that the steam may not escape. At the same time, that pressure may be taken off from the upper surface of the piston, *d* opens that the steam may escape, and *c* shuts that none may enter. When the piston is to be forced downward all this is reversed—*c* opens to admit the steam, *d* shuts to prevent its escaping; and below, *b* is opened to let the steam escape, and *a* is shut to prevent any from entering. This is the plan of what is called the high-pressure engine. The low-pressure engine differs from it in having the steam, as it escapes from the cylinder, pass into water to be condensed. The latter requires less pressure of steam to work it, and therefore is the safest. The manner in which the motion of the piston is made to work various kinds of machinery I need not stop to explain, especially as exemplifications of it may be seen in every quarter.

295. **Communication of Heat.**—Heat has a constant tendency to an equilibrium. If therefore any warm substance be in the neighborhood of one which has less heat, a flow of heat from the former toward the latter takes place. Now this communication of heat occurs in three different ways, called Convection, Conduction, and Radiation. I will speak of each of these separately.

296. **Convection.**—This mode of diffusion of heat is in operation in those substances whose particles are movable among each other—viz., liquids and aeriform substances. I have already alluded to examples of this mode in speaking of the movements which heat causes in these substances. The heat goes along with the particles which are moved, or is *conveyed* along with them, and

hence the term convection. In this movement the heated particles always ascend, for the reason given in § 275. Of the multitude of examples of convection I will present but a few.

In the upward current about a stove-pipe you have an example of convection, the heat generated being carried upward by the particles of this current. This being so, the heat of a stove has no effect upon the air *below* it by convection, though it does have by radiation, as you will soon see. Any hot fluid becomes cool chiefly by convection. The air coming in contact with it taking some of its heat rises, and other air comes in its turn to be also heated, and so on till the fluid becomes of the same temperature with the air, and then the currents of air cease. The liquid cools more rapidly by stirring it, because the air is brought into contact with a greater extent of surface, and so the heat is conveyed away more rapidly. The result is the same whether we disturb the surface by stirring it or by blowing upon it. In the latter case, however, the effect is increased by making the air to come more rapidly upon the disturbed surface. So in fanning, it is the bringing of the air faster upon the surface of the body that causes the more rapid convection of heat from it. Every one must have observed the fact that a buckwheat cake cools much more quickly than a flour or rice cake. It is because it has so many pores and little projections, and so presents a much larger amount of surface to the heat-conveying air than the smoother and more solid cakes. Viscid fluids, as molasses, oil, etc., when heated do not cool as readily as water, because their particles are not as movable, and therefore heat is not conveyed as rapidly upward to be given off to the air.

297. **Conduction.**—In this mode of diffusion the heat goes through or among the particles of substances. For example, if one end of a bar of iron be held in the fire, it travels through or among the particles to the other end.

The gradual progress of the heat may be seen by the following simple experiment: Take a rod of iron and attach to it, as seen in Fig. 211, some little balls of wood by means of wax. By heating one end with a lamp the balls will drop one after another as the heat passing along melts the wax which holds them.

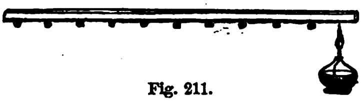


Fig. 211.

298. **Conductors and Non-Conductors.**—Heat is conducted more rapidly through some substances than through others. There is great variety in this respect. There is considerable among those which are reckoned as good conductors, as is shown by the experiment represented in Fig. 212. Here are cones of the same size of seven different substances — copper, iron, zinc, tin, lead, marble, and brick —all tipped with a little wax, and placed on a stove. The wax will melt on the copper cone first, showing that this is the best conductor of them all; and on the brick one last, showing that this is the poorest conductor. The conducting powers of the rest are according to the order in which I have mentioned them.

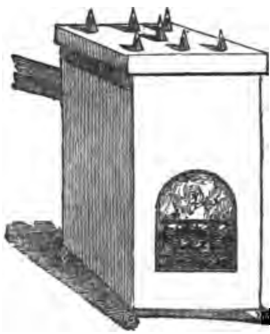


Fig. 212.

Those substances which allow heat to pass through them very slowly are called non-conductors. The term, though convenient, is not a strictly correct one, for there are no substances which do not conduct heat in some degree. Wood is one of these poor conductors, and hence wooden handles are put upon various instruments and vessels that are used about fires, as the soldering irons of the tinman, the metallic tea-pot, etc. As cloth is a non-conductor, the holder is used in taking off the tea-

kettle and in using the flat-iron. Glass is so poor a conductor that if you hold a rod or tube of it across the flame of a spirit lamp or gas burner, and heat it even to redness, you can place your fingers very near to the heated portion with impunity. I had occasion to-day to bend a small glass tube in this way, and I observed some water in it quite near to the heated part which remained undisturbed through the process. It is the non-conducting quality of glass that makes it so liable to break, when it is thick, if it be exposed to any sudden change of temperature. For example, if hot water be poured into a thick glass vessel, the inner surface is quickly expanded; but the outer surface not expanding with it, because the heat is not readily conducted through, this irregularity in expansion causes a fracture. It is for this reason that the flasks, retorts, etc., used by the chemist are made very thin, especially where the heat is to be applied.

299. **Davy's Safety-Lamp.**—One of the most beautiful applications of the conduction of heat we have in the Safety-Lamp of Sir Humphrey Davy, an invention which has been the means of saving the lives of multitudes of miners. It is represented in Fig. 213. With this lamp one can go into the midst of the most explosive gases with impunity. Now all that prevents the flame within from setting on fire the gases without is a covering of wire-gauze. This, being a good conductor, conducts off the heat of the flame within so rapidly that it can not go through the openings *as flame*, and so does not set fire to the gas without. The fact upon which the construction of this lamp was based was discovered by trying many experiments. Among them were the following: A piece of wire-gauze was held over a candle so that its flame struck against it. The smoke is-

Fig. 213.

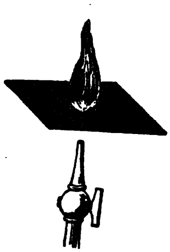


Fig. 214.

sued above, but no flame. Then a stream of gas was allowed to pass through the gauze, as seen in Fig. 214, and was set on fire above. It burned without inflaming the gas below.*

300. **Relation of Density to Conduction.**—Generally the more dense a substance is the better is its conduction of heat. Thus the metals are better conductors than wood, marble than brick, the solids than liquids, and liquids than aeriform substances. We have frequently a good illustration of the difference between stone and brick as conductors in the melting of snow on sidewalks. If a light snow fall in the spring, after the earth has become somewhat warm, you will see it melted from the stone walks much before it is from the brick ones. This will be especially the case if the snow be melted mostly by the warmth of the earth without the agency of the sun. The explanation is obvious. The stone is a better conductor than the brick, and therefore the heat of the earth comes up through the former more rapidly than through the latter.

301. **Conduction in Liquids.**—That liquids are poor conductors of heat may be shown by an experiment or

* As in the case of many other inventions, so here the same idea was originated and put to practical use by more minds than one. George Stephenson, who from being a common engine-wright in a colliery rose step by step till he invented the locomotive, constructed a lamp which illustrated in another way the same principle as the lamp of Davy does—in other words, he invented another safety-lamp. But this does not in the least detract from the glory which the invention has given to the name of Davy, for each acted independently of the other. In Davy's case, it is to be remarked, there was a long course of scientific reasoning and investigation which led him at length to the invention, the record of which is exceedingly interesting. No invention or discovery is made without thought, though accident may suggest the thought; but here is an invention which, without any suggestion by accident, was evolved by laborious and long-continued thought, proceeding step by step to its conclusion.

two. If a thin glass tube closed at one end be filled with water, and the heat of a spirit lamp be applied to its upper portion, as seen in Fig. 215, though the water at this portion may be made to boil, there will not be the least movement in the lower part. This will be very obvious if you have some amber-dust in the water. Again, let a little water be frozen in the lower part of the tube by placing it in a freezing mixture, and introduce a little oil, and then over that some alcohol. Hold now the tube over the chimney of a lamp, as represented in Fig. 216, until the alcohol boils. The ice in the bottom of the tube will not be in the least affected, and the oil will be but slightly heated. If the heat were to be applied in either of the above cases at the lower part of the tube the result would be different, because convection would then operate in the diffusion of the heat.

Fig. 215.

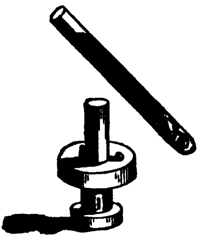


Fig. 216.

302. **Air as a Non-Conductor.**—Heat is rapidly diffused in air by convection; but it is only when the air is free that this can be done. When the air is confined in spaces or pores, or among fibres, heat makes its way through it very slowly, for it can be diffused through it then only by conduction. The variety of ways in which air is of service to us as a non-conductor is almost endless. I will notice some of them.

303. **Double Windows.**—The efficacy of double windows depends upon the confined air between them. In the case of the single window a great deal of the heat inside is lost in this way: The warm air of the room which comes in contact with the window imparts to it some of its heat, and, being thus cooled and therefore condensed, passes downward. As this process goes on continually this downward current by the window is

constant. The current outside is in the opposite direction. The heat imparted to the window is taken up by the cold air, and as it thus becomes warmer it passes upward. And this upward current outside is as constant as the downward current inside. Now nearly all this is prevented by the non-conducting quality of confined air in the case of double windows. If a pane were taken out from the upper part of the inner window, and another from its lower part, the inner window would be of little use, for then the heat of the air in the room would be continually diminished by convection, as when the window is single. The warm air would pass in at the upper opening, and, being cooled, pass down through the lower one.*

304. **Air as a Non-Conductor in the Walls of Buildings.**—The spaces included between the outer wall of a building and the plastering inside being filled with confined air, prevent the heat of the air in the apartments from passing off readily through the wall. A house built of brick or stone, with the plastering placed directly upon the inside of the wall, would be kept warm with difficulty in winter, because the solid wall would so readily conduct off the heat to the external air. So, also, such a house would be very warm in summer, because the heat of the sun and of the external air would be so rapidly communicated to the air of the house. In this connection I will mention a contrivance to prevent the spreading of fires in blocks of buildings, which, though very effectual, is seldom made use of, partly because it

* I will mention here a contrivance that I once adopted for a small conservatory, which I wished to keep warm from the heat of a room to which it was adjoining. In each space of the window-frames were put two panes of glass, there being nearly half an inch of space between them. In this way I secured all the benefit of double windows with less expense and a less cumbrous arrangement. In mentioning this contrivance now and then, casually, I have found that a few others have thought of it, and adopted it with the same success that I did.

occasions some trouble and expense, and partly because it takes up a little room. It is this: A small space is left in the division wall between each two houses from top to bottom, containing, of course, a body of confined air, that is, if the space be entirely shut in, which is as essential here as in the case of the double windows. With such an arrangement the interior of one house may be entirely consumed without communicating sufficient heat through the confined air to set on fire the other.

305. **Fur, Hair, and Feathers.**—Animals that live in cold climates are provided with suitable coverings for their protection. Quadrupeds, for example, are covered with fur, and birds have an abundance of downy feathers. These coverings have no warmth in themselves, though in common language we speak of them as being warm. They are simply non-conductors, and so prevent the heat which is made in the body of the animal from escaping as fast as it otherwise would. But why are they non-conductors? It is not because the substance of which they are made is a non-conductor, but because among their numberless fibres is partially confined that great non-conductor, air. Let the fur or down be condensed into a thin hard plate upon the animal, and it would prove of little service as a protection against cold. Down is much more abundant on the birds of cold climates than on those in warmer regions, because more air can be confined among the fibres of down than among those of common feathers. Quadrupeds that are natives of warm climates generally have hair instead of fur. When therefore the horse is taken to a cold climate he requires in winter the defense of a blanket; and the ox needs under the same circumstances to be better housed than he ordinarily is. As the elephant is a native of a climate positively hot, his hairs are scanty and coarse. Formerly there were elephants in the cold regions of Siberia, as has been ascertained by remains found there. But the elephant of Siberia had under its hair, close to

the skin, a fine wool to protect it against the cold. Animals that live in cold climates have their coverings become finer in fibre in the cold season of the year, to give them the additional protection which they then need. And animals with a furry covering, if they are carried into a warm climate, have their fur become coarse, and approximate the condition of hair.

306. **Clothing.**—Man has no covering to guard him against cold, because he is capable of contriving clothing suitable to the various degrees of temperature to which he may be exposed. The object of clothing is not to make the body warm, but to keep it so. The heat of the body is generated continually within itself, and under all circumstances this heat is maintained quite uniformly at 98°. This, you see, is a much higher degree than the atmosphere ordinarily has. We are all the time, then, giving off heat to the air around us, except when the air gets up to 98°. We are comfortable only when we are giving off heat to a considerable amount, for the point of temperature which is most agreeable to us when we are at rest is 70° or a little less, that is nearly thirty degrees below the temperature of our bodies. When the temperature is below this we need extra clothing. In making choice of clothing for various degrees of temperature we practically apply the principles which I have developed. Those articles of clothing which can confine or entangle, as we may say, the largest quantity of air among their fibres are the best non-conductors, or, in common language, are the warmest. So, too, loose clothing is warmer than tight, on account of the amount of air between the clothing and the body. Thus a loose glove is much warmer than a tight one. The same general fact is exemplified in the coatings of straw which we put upon tender trees and shrubs in winter. It is the air that is confined in the tubes of the straw which makes these coverings so effective a defense. It is probably the air in the pores of the brick which makes it a

poorer conductor than stone, as illustrated by the fact stated in § 300.

307. **Cocoons.**—Many insects pass through their pupa or transition state in cocoons. When this is done during warm weather, as in the case of the silk-worm, the cocoon is simple. But when the pupa state lasts through the winter special provisions are made in the arrangements of the cocoon to guard the insect against the cold. I will cite as an example the cocoon of one of our largest moths, the Cecropia. This cocoon, fastened to some shrub, keeps its inmate secure from the rigors of the winter by a very beautiful arrangement. The real cocoon is similar to that of the silk-worm; but it has a very dense air-tight outer covering, and the space between these two coverings of the pupa is filled with a loose substance, which has air, of course, mingled with its fibres, and acts, therefore, the part of a blanket for the insect.

308. **Buds of Plants in Winter.**—In the latter part of summer buds are formed on trees and shrubs, and these contain the germs of the branches, leaves, and flowers which are to come out the next year. These of course must be guarded against the cold of winter, and it is done very much as the pupa is guarded in the cocoon. Each bud you can see has a covering of scales which is air-tight, and inside of this there is a soft downy substance, the blanketing of the bud. In these coverings, which have been called by some one the "winter-cradles" of the buds, the infant vegetation of another year rocks back and forth in the wintry winds secure from the cold, till the warm sun of spring wakes its hidden life into activity.

309. **Snow a Protection to Plants.**—Snow is a good blanket to the earth, keeping its warmth from escaping into the cold air. This is because it contains mingled with its feathery crystals such a quantity of air. If snow come early, before the ground and the plants in it have

become frozen, it will keep them from freezing through the winter, if it remain during all that time. It is curious to observe the peculiar arrangement of the snow in the arctic regions for the preservation of vegetation. First in the autumn come soft light snows covering up the grasses, and heaths, and willows. Then as winter advances there are laid on top of these the denser snows, making a compact, stout roof over the lighter snows in which the scanty but precious vegetation of those regions is imbedded. On top of this roof are deposited the snows of spring. As these melt the water runs off from the icy roof down the slopes, leaving untouched the plants underneath, which lie there alike secure from the rush of waters and from the nightly frosts until the season is sufficiently advanced to bring them out with safety from their concealment. Then the icy roof melts, and with it the light snows that have so long encircled the plants, and the sun wakes them from their long sleep to a new life.

310. **Influence of the Conduction of Heat on Sensation.**—If you place your hand upon fur hanging at the door of a fur-store it does not feel as cold as the wood from which it hangs, and the wood does not feel so cold as the iron bar of the shutter close by. Why is this, when these substances are exposed to the same atmosphere, and really have the same temperature? It is because the iron conducts the heat from your hand more readily than the wood, and the wood more readily than the fur. So the iron handle of a wooden pump feels colder than the pump, and the pump colder than the snow around it. For the same reason, in a cold room the rug or the carpet will not feel as cold as the poker and the hearth. If water has stood long enough in a room to be of the same temperature with the air of the room your hand will feel colder in the water than in the air, because the water is the better conductor. So much for the sensation of *cold*. On the other hand, when substances are

so heated as to give us the sensation of heat, the conductors do this more than the non-conductors. As they receive heat readily they also readily impart it. For this reason, with a brisk fire the hearth-stone feels very hot, while the rug before the fire does not.

311. **Radiation of Heat.**—Every substance sends heat into space constantly in straight lines in every direction. These lines are radii, and hence the term radiation is applied to heat diffused in this way. It is very obvious in regard to the sun that it radiates heat in all directions. The same can be seen in the case of a heated iron ball. In whatever direction you hold your hand, above, below, or laterally, you feel the heat. And it makes no difference whether the ball be red-hot or not. That is, heat is radiated either with or without light. When a room is warmed by a furnace it is warmed altogether by convection; but when it is warmed by a fire, either in a fireplace or a stove, we have both convection and radiation. The heat which we receive from the sun comes altogether by radiation.

312. **Connection between Heat and Light.**—The heat and light of the sun pass together through transparent substances, as air, glass, water, etc., without heating them to any extent. Thus, when the heat is transmitted through a lens, § 272, the lens is little heated, that is, it lets almost all the heat pass through it. The air is heated by the sun, but not directly to any amount. It is heated indirectly in this way: the rays of the sun passing through the air heat the earth, and then the air receives a part of this heat from the earth, which is diffused through it by convection.

It is otherwise with heat that comes from a common fire. It does not seem to be so thoroughly united with the light, and therefore readily parts company with it, as we may say. While the heat and light of the sun go together through all transparent bodies the heat of a fire will not go with its light through all of them. So while

the heat of the sun does not warm the glass through which it passes the heat of a fire will warm it, and therefore glass is an effectual screen against it. In some operations in the arts a mask of glass is sometimes worn to ward off the heat. The connection of light and heat will be farther noticed when I come to treat of light.

313. **Relation between Radiation and Absorption.**—All surfaces that radiate will absorb also equally well the heat that is radiated upon them. All rough and dark surfaces both absorb and radiate freely; but all light-colored and polished surfaces do both slowly. For this reason the black, rough tea-kettle is well fitted to heat water in; but it is not fitted to retain the heat in the water. On the other hand, the bright, polished teapot absorbs heat poorly, but retains it well.

314. **Reflection of Heat.**—Radiated heat is reflected; and here, as in the case of motion, § 206, and of sound, § 260, the angles of incidence and reflection are equal. Some interesting experiments in relation to the reflection of heat can be tried with concave metallic mirrors. Thus, if we take two such mirrors, as represented in Fig. 217, and place in the focus of one a thermometer, and in the focus of the other a small flask of hot water, or a heated iron ball, the mercury in the thermometer will rise, although the mirrors may be many feet apart. Observe how the effect is produced. Rays of heat go from the flask directly toward the thermometer, as represent-

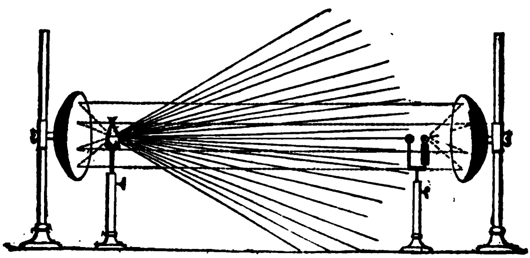


Fig. 217.

ed by the lines in the figure; but that the effect does not come from these can be proved by removing the mirrors, leaving the flask and thermometer just as they are. When the experiment is tried in this way no effect is produced on the thermometer, because it is too far from the source of heat, the flask, to receive any perceptible influence in this way. The effect comes from the rays of heat which go to the mirror near the flask, and are reflected to the other mirror, and then are reflected upon the thermometer, all of which is represented by the dotted lines. There is another way, besides that already mentioned, of showing that it is not the *direct* rays that produce the effect. After arranging the apparatus put a screen between the thermometer and the mirror near it, and the effect will be prevented because the reflection is cut off. If a piece of ice be substituted for the flask of hot water the thermometer will fall—an effect opposite to that produced in the previous experiment. This would seem to show that cold is radiated, but as there is no such thing really as cold, § 270, the effect must be attributed to the radiation of heat from the thermometer to the ice. If a hot ball be placed in the focus of one mirror and a piece of phosphorus in that of the other, the phosphorus will be set on fire, though the mirrors may be twenty or more feet apart.

The reflection of heat may be exhibited very prettily with the experiment represented in Fig. 218. A sheet

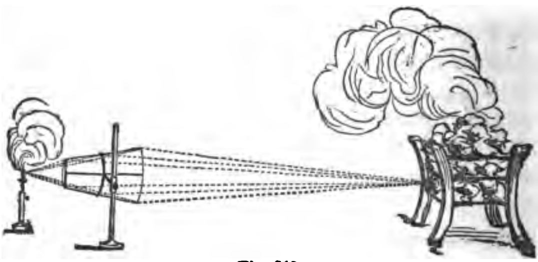


Fig. 218.

of bright gilt paper is rolled up in the shape of a funnel, with the metallic side inward. Holding the larger end toward a fire, the rays of heat coming from the fire into the funnel are reflected toward a central line, and so pass out of the smaller end of the funnel concentrated. If, now, a bit of phosphorus or a lucifer match be held a little distance from this end of the funnel it will be set on fire.

315. **Formation of Dew.**—It is by the radiation of heat that dew is formed. The earth is constantly radiating heat into space as well as the sun. In the daytime it receives a great deal more than it radiates. But at night this is reversed, and the earth is cooled. The cooled earth condenses the moisture in the air which is in contact with it, and so the moisture is deposited. If the weather be very cold this is frozen, and then we have frost instead of dew. You observe that the dew does not *fall*, though this is the ordinary expression. Its formation is analogous to the deposit of moisture which we so often witness in a hot day in summer on the outside of a tumbler containing cold water. As the cold tumbler condenses the moisture in the air, so does the earth at night, it being cooled by radiation, condense the moisture which has accumulated in the air by evaporation during the heat of the day.

There are some circumstances which have an influence upon the deposition of dew and frost. Less is deposited under a tree than outside of it, because all the heat which radiates vertically upward from under the tree is radiated back again by the tree. Hence the efficacy of a covering over plants as a defense against frost. Clouds operate in the same way, and for this reason no dew or frost is deposited in a cloudy night. Neither is any deposited in a very windy night, because the moving air promotes evaporation, and thus prevents the accumulation of moisture.

Dew is deposited in different amounts on different

substances. This is owing to a difference in radiation. Grass and leaves radiate heat better than earth, and earth better than stone; and therefore while stones and gravel-walks may be dry or nearly so, the loose earth may be moist and the grass and leaves thoroughly wet. So you see that not even the dew, plentiful as it is, is wasted by the Creator, but is deposited just where it is wanted to refresh the parched earth and its vegetation.

316. **Gideon's Fleece.**—If you lay a fleece of wool upon the ground, it is so poor a radiator of heat that no dew will be deposited upon it, although there may be an abundance of it on the grass and leaves in its neighborhood. But this was reversed in the case of Gideon's fleece. The laws of nature were set aside, and the fleece was wet with dew while all around was dry.

317. **Dew-Point.**—What is called the dew-point of the air is that degree of temperature to which any substance must be brought down in order to have dew deposited upon it. This depends upon the amount of water there is in the atmosphere. The more there is the higher is the dew-point. When water condenses on a cold tumbler in a hot day there is much more water in the air, and the dew-point is higher, than when no moisture is condensed upon the tumbler. So after a very hot clear day the earth needs not to be much cooled to produce a deposit of dew, because the air has become so highly charged with moisture through the evaporation of the earth under the hot sun. We can very readily at any time ascertain the dew-point. Take a glass of water, and, having a thermometer in it, drop into it some pieces of ice, and watch the outside of the glass. As soon as it begins to be dimmed with moisture look at the thermometer, and you have the dew-point.

318. **Freezing Mercury.**—Mercury can be frozen by radiation when the cold is excessively severe, although the thermometer may indicate a temperature considerably above −39°, the degree at which mercury freezes.

Suppose that in a clear, still night the temperature of the air is at $-20°$. In order to freeze the mercury it must be cooled down 19 degrees below this. Now this can be done by surrounding the mercury with some good non-conductor, as charcoal. This cuts off the supply of heat to the mercury, while it is all the while giving off heat into space by radiation. In like manner can ice be formed in an atmosphere that is above the freezing point, and this is often done in warm climates.

319. **Latent Heat.**—You have seen, § 270, that our sensations do not inform us accurately of the amount of heat in any substance. The same is also true of the thermometer. This only indicates the *sensible* or free heat. There may be a great deal of heat locked up, as we may say, in the substance, which can be brought out or made free by some change in the substance. This heat thus locked up is called *latent* heat.

320. **Capacity for Heat.**—The more heat a substance can take in and render latent the greater is its capacity for heat, as it is expressed. Thus water has a much greater capacity for heat than mercury. This can be proved by various experiments. Thus, if we take two vessels just alike, and having, the one a certain quantity of water in it, and the other the same quantity of mercury, and expose them to the same degree of heat, it will take much longer to raise the water to any specified temperature than the mercury. Why is this, when they are both receiving the same amount of heat? It is because the water renders a much larger portion of the heat latent than the mercury does. We can reverse this experiment. Take these same vessels with their contents raised to the same temperature, as indicated by the thermometer, and allow them to cool in the air side by side. The mercury will cool much faster than the water, because it has much less of latent heat to part with. The difference in capacity for heat between water, oil, and mercury may be shown by the experiment represented in Fig. 219. A

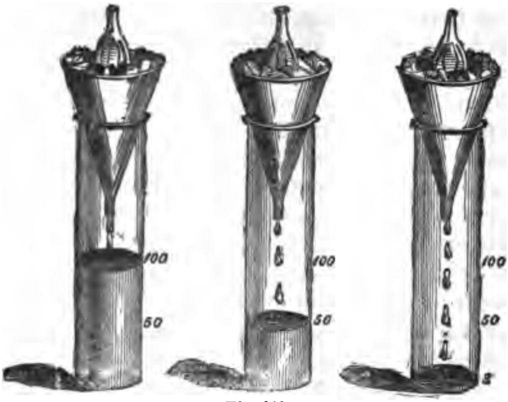


Fig. 219.

pound of water is put into one Florence flask, a pound of oil into another, and a pound of mercury into a third. They are all heated to 212°, and are then placed in funnels filled with pounded ice, the funnels resting in glass jars of the same size. Now in cooling these fluids down to a certain point, say 32°, different amounts of the ice will be melted, in the proportions of 100 and 50 and 3. This shows the proportions of latent heat in them which become sensible or free as their temperatures are lowered.

Fig. 220.

321. **Relation of Latent Heat to Density.**—The more dense a substance becomes the less is its capacity for heat. The heat produced by hammering iron is the latent heat rendered free by condensation, this lessening the capacity of the iron for heat. The same thing can be better illustrated in the condensation of a very compressible substance, as air. In Fig. 220 you have represented a glass syringe with a closed end. If there be placed in this end a little bit of cotton wool moistened with ether, and the piston be forced downward very quickly, the ether will be

set on fire. This is because the compression of the air lessens so much its capacity for heat that a great deal of its latent heat is made sensible or free. The heat which is concealed in it in its ordinary state is, as we may say, fairly squeezed out, as you would squeeze out the water that is concealed in the interstices of a sponge.

322. **Coldness of Air at Great Heights.**—You learned in § 152 that the atmosphere is thinner the farther you go from the earth. It is very thin, therefore, on the summits of high mountains. This is the chief reason why it is so cold there, for the rarer the air is the greater is its capacity for heat, and the more of sensible or free heat therefore can it render latent.

323. **Relation of Latent Heat to the Forms of Substances.**—Whether a substance shall be in the form of a solid, liquid, or gas depends upon the amount of heat which is latent in it. If you take a piece of ice and melt it in a vessel, the ice and the water in the vessel that comes from the melting of the ice are both at 32° until the ice is all melted. But all this time heat is being communicated to the ice and water. What becomes of it? It is all taken up by the ice as it changes from its solid to its fluid state, and becomes latent in it. In fact *every particle of ice must have just so much of latent heat in order to become fluid.* So, also, if water be heated to the boiling point, 212°, and be kept boiling, the water will remain at that point till it is all vaporized. All this time the water is receiving heat, which, instead of raising its temperature, is becoming latent in the particles as they change from their liquid to their vaporous state. As I said of the change from the solid to the liquid state, so here, *every particle of the liquid must have just so much of latent heat in order to become aeriform.* Whenever therefore any solid substance becomes liquid, or liquid becomes aeriform, heat is absorbed and becomes latent. So, on the other hand, whenever any aeriform substance becomes liquid, or liquid becomes solid, latent heat is giv-

en out, and becomes free and sensible. The freezing of water, then, is a source of warmth to the air in its neighborhood—a fact which is practically made use of when tubs or pails of water are placed in conservatories to keep plants from freezing; and the thawing of snow and ice is a source of cold, as is exemplified by the chilliness of the air occasioned by this process.

324. **Clouds and Latent Heat.**—The water of which clouds are composed is heavier than air. Why, then, does it remain suspended? Why is it necessary that it should be collected into drops in order to have it fall? This question can be answered by looking at the manner in which clouds are formed. A cloud, I have stated in § 288, is made up of minute vesicles or bubbles containing air. Now the air in these bubbles is lighter than the air that is around the cloud, because it is warmer. But how does it get its heat? In order to understand this observe what the bubble is made from. It is made from the water which was in the air in a state of vapor, or in its aeriform state, for this is the state of water that is evaporated and dissolved in the atmosphere. But when it forms the vesicle it goes out of this state and becomes a liquid, for the wall of the vesicle is a liquid wall, just as the wall of a soap-bubble is. Now in passing out of the aeriform into the liquid state some latent heat must be made sensible. What becomes of this sensible heat? It just heats the air in the vesicle, and so makes it like a heated air-balloon. So all clouds are collections of innumerable heated air-balloons, and the reason that some clouds are higher up than others perhaps is that their balloons have warmer and therefore lighter air in them.

325. **Freezing Mixtures.**—The intense cold produced by these mixtures is the result of the change of free or sensible heat into latent. For example, when salt and snow are mingled together a melting of the two is quickly produced. In this sudden change of a solid into a

fluid a great quantity of heat must be rendered latent, and therefore there will be a great loss of sensible heat by whatever the freezing mixture comes in contact with. The process here, you see, is the opposite of solidification in relation to latent heat. A portion of the snow, after melting with the salt, becomes solid ice. Why is this? It is because it gives up its sensible or free heat to portions of the snow that are in the process of melting and are therefore making heat latent.

326. **Cold from Evaporation.**—If you pour a little ether into the palm of your hand it will rapidly disappear in vapor, producing a very cold sensation. This sensation occurs because, in the change of the liquid into the vaporous or aeriform state, some of the sensible heat of your hand is abstracted to become latent in the vapor. The evaporation of water also produces cold, though not as decidedly as ether, because its change into vapor is not so rapid at ordinary temperatures. We make a practical use of the evaporation of water in many different ways. Thus we sprinkle water in a hot day upon the floors of piazzas, steps, etc., that the evaporation may make much of the sensible heat about our houses latent. For the same purpose, in hot climates, apartments are often separated from each other by mere curtains, which are occasionally sprinkled with water. So the inhabitants of such climates often cool their beverages by keeping a wet cloth for some time wrapped around the vessels that contain them. Evaporation is an important remedy for many cases of disease. For example, if the head be hot, a steady application of a wet cloth to the forehead, though a simple remedy, is generally effectual, and sometimes is very important. Most people make the application in a wrong manner. They put on several thicknesses of cloth, when a single thickness is the best, because it will best secure the evaporation, which is the cause of the relief afforded.

327. **Freezing in the Midst of Boiling.**—It is from the

quantity of heat rendered latent by evaporation that water can be frozen in the midst of boiling ether; and, paradoxical as it may seem, the boiling of the ether is the cause of the freezing. The experiment is performed in this way: Place a test-tube or a little thin vial with water in it in the midst of some ether in a shallow vessel under the receiver of an air-pump. On exhausting the air the ether will boil, evaporation taking place rapidly because the pressure of the air is taken off from the ether. Now as the ether passes into vapor it extracts so much free heat from the vial of water that the water is cooled down to the freezing point, and so becomes solid. Water can be frozen even by its own evaporation. It is done in this way: Let a shallow vessel, *b*, Fig. 221, contain a little water, and the vessel *c* oil of

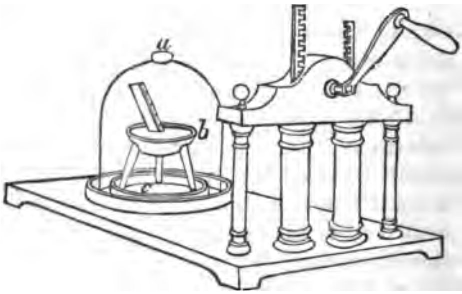


Fig. 221.

vitriol or sulphuric acid. When the air is exhausted, the pressure of air being taken off from the water, vapor rises from it freely. As the sulphuric acid has a great attraction for water it absorbs this vapor, and so vapor continually rises from the water the more rapidly because what is formed is absorbed, instead of remaining to make pressure on the water. The result is that this rapid formation of vapor, requiring that a great quantity of heat should be made latent, at length abstracts so much heat from the water that remains that this becomes solid.

328. Degree of Heat Endurable by Man.—It was formerly believed that the human body could not endure with impunity, even for a short time, a much higher degree of temperature than that which is met with in hot climates. But in the year 1760 it was accidentally discovered that a much higher temperature than this could be endured. An insect was destroying at that time the grain gathered in some parts of France, and it was found that if the grain was subjected to a certain high degree of temperature the insect was killed, and yet the grain was not injured. In trying some experiments in regard to this matter the experimenters wished to know the point at which the thermometer stood in a large oven. A girl attending on the oven offered to go in and mark the thermometer. She did so, remaining two or three minutes, and the thermometer was at 260°, that is, 48° above the boiling point of water. As she experienced no great inconvenience from the heat she remained ten minutes longer, when the thermometer rose to 76° above that point. These facts were published, and prompted scientific men to try other experiments. In England, Dr. Fordyce, Sir Charles Blagden, and others, went into rooms heated even to 240° and 260°, and remained long enough to cook eggs and steaks, and yet themselves suffered little inconvenience. The pulse was quickened, the perspiration was very profuse, but the heat of the body, as ascertained by putting the thermometer under the tongue the moment they came out, was scarcely raised at all. The air in which they were roasted eggs quite hard in twenty minutes, and when it was applied by a pair of bellows to a steak it cooked it in thirteen minutes. The question arises, how is it that this high degree of heat did not produce more effect upon the body? One reason is that the heat of the air in the immediate neighborhood of the body was continually reduced by the evaporation of the free perspiration, sensible heat being thus converted into latent. Another reason is that the

air is not a good conductor, and therefore did not communicate its heat readily to the body. Dr. Fordyce and his friends found that they could not touch with impunity any good conductor, as the metals, and they were obliged to wear upon their feet some non-conducting substance.

329. **Formation of Ice.**—Before dismissing the subject of heat I must notice the grand exception which we have to some of the operations of heat in the formation of ice. Heat generally produces expansion. But in the case of water this law of expansion is set aside, and the reverse is established. This is done, however, only within a small range of temperature, viz., from the freezing point up the scale about seven degrees. In all degrees above that the usual expansion by heat takes place. The exception occurs at this part of the scale for a special purpose, viz., *that water, in distinction from other substances, shall become more bulky, and therefore lighter, as it takes the solid form.*

330. **Description of the Process of Freezing.**—In order to make the process of freezing clear to you I will describe it as it ordinarily occurs, that is, from the action of cold air upon the surface of water. The uppermost layer of the water imparts some of its heat to the air in contact with it. This air rises and colder air takes its place, which being warmed in its turn rises to make way for more of the cold air. You have therefore a constant current of warmed air upward from the water. In the mean time there is a current of a different character in the water—a downward one. As fast as the water at the surface parts with heat to the air it falls, other warm water taking its place, to cool in its turn and go down. This falling of the cooled water goes on regularly until a portion of water becomes cooled down to 39°, that is, 7° above the freezing point. This layer does not sink, but remains at the surface, for it is lighter than the warmer water below. This is because the law that heat

expands matter is now reversed. Beyond this point of the thermometer the colder the water is the lighter it is. As the cooling now goes on from the air coming, as before, in successive layers to the water, the cooled water at the surface continually increases. At first it is a mere single layer of particles, but after a while it is quite a body of cold water lying on the warmer water below. At length some of it is cooled down to 32°, the freezing point, and a thin film of ice now forms. The state of things just at this stage of the process may be represented by a simple diagram, Fig. 222. Let the line *a* represent the film of ice. The space between *a* and *b* is the portion of water cooled down below 39°. The space below *b* is occupied by the water which is above this temperature. In the space between *a* and *b* the cooler the water is the nearer it is to the surface. That is, from the line *b*, where the water is exactly at 39°, as you go upward, the water lessens in temperature, it being successively 38°, 37°, 36°, etc., till, just in contact with the film of ice, *a*, it is at 32°. The ice goes on to thicken gradually by additions below. But it is to be remembered that ice is a good non-conductor, so that the very first layer of ice makes the cooling of the water proceed more slowly than before. And the thicker the ice becomes the slower is the cooling. This secures against too great a formation of ice.

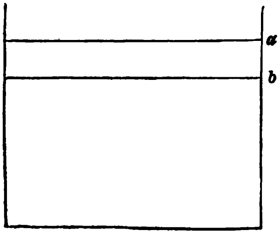


Fig. 222.

331. **Why the Above Exception to Expansion by Heat Exists.**—That we may see the reasons in part for the grand exception to the general law of expansion by heat which I have illustrated, let us see what would be some of the results if the exception did not exist. In that case the process of freezing would be as follows: The water

would communicate its heat from the surface to the air, as before described, and there would be a constant downward current of the cooled water. When any portion of the water became cooled by the air down to 32°, it would become ice, and would sink to the bottom. And after the process of freezing had once begun, there would be a continual accumulation of ice at the bottom so long as the air remained cold enough to cool the water with which it comes in contact down to 32°.

The result may be stated in the general thus: Freezing would not begin so quickly as it now does; but when once begun it would prove very destructive. It would not begin as soon, because the whole of any body of water must be cooled down to just this side of 32° before it could begin. This would not take long where the water is shallow, but it would where it is deep. All shallow bodies of water, then, would be frozen up quite early in the winter; and as water is a poor conductor, and thawing must go from above downward, some of them would not be thawed out again fully till quite into the next summer, if even then. And where the water is quite deep ice would at length begin to form, and when formed it would be exceedingly slow in thawing. In some cases it would never be thawed with such a body of non-conducting water to guard it against the warmth above. It is easy to see that the heat of spring and summer would not thaw out any thing like the quantity of ice that it now does. The reign of ice and snow on our earth would therefore be vastly more extensive than now, and what is worse, it would be extended more and more every year. Under such circumstances there would be great destruction of both animal and vegetable life. I will mention, however, but a single item, as it would occupy too much space to go into this subject with any fullness. In the water under the ice, which is always above 39°, except that which is close to the ice when freezing is going on, there is a vast amount of busy life

which would be destroyed if ice were formed at the bottom, chilling all the water above.

332. **Why the Freezing Point is at 32°.**—If the freezing point of water were higher than 32°, freezing would occur so early in the autumn, and the ice and snow would last so late in the spring, that the season would be too short to raise our supplies of fruits and grains. If, on the other hand, it were at a lower point, the earth would not have the protection of its light coat of snow, but instead would be chilled by rains so cold that barrenness would be the result. The multitudes of animals, too, that now live so securely in the water, some of them even with the ice above them, would all perish with the cold.

333. **Force of Expansion in Ice.**—As ice occupies one seventh more room than the water from which it is formed, it exerts in its formation an expansive force which under various circumstances produces varied and often remarkable results. Of the many experiments which have been tried to show the force of this expansion I will mention but one. A bomb-shell was filled with water at Montreal, and closed with an iron plug which was driven in with great force. The plug was thrown a distance of 400 feet by the expansion when the water froze. This expansion is sometimes an inconvenience to us, as in bursting water-pipes; but besides the great service which it does in the earth, already noticed, it is of service also in loosening the soil, and in supplying it with requisite ingredients from the rocks by breaking them up and pulverizing them in small quantities from year to year.

CHAPTER XIV.

LIGHT.

334. **Nature of Light.**—We do not know what light is. There are two suppositions in regard to it. One is that of Sir Isaac Newton, called the theory of *emission*. According to this light is a substance, but so ethereal that it has no weight, and is capable of passing through various substances of even great density. The other supposition is what is called the *undulatory* theory. The advocates of this, which is now quite generally received, believe light to consist of undulations, waves, or vibrations in an ether which is supposed to exist every where, pervading all space and every substance. You perceive an analogy here to sound, the vibrating medium in the case of sound, however, being always some palpable substance—solid, fluid, or aeriform. Heat is supposed, as stated in § 271, to be a vibration of the ethereal substance, as light is, though the two vibrations must of course be somewhat different in character. Any body that is capable of communicating the light-vibration to this ether is said to be *luminous*.

335. **Sources of Light.**—The chief source of light to our earth is the sun, which is a permanently luminous body. Then we have the light of combustion in its various forms. Electricity is another source of light. Light is sometimes emitted during decay or putrefaction of some substances. Some animals—as fire-flies, glow-worms, and phosphorescent animals in the sea—have the power of emitting light.

336. **Light Moves in Straight Lines.**—Light, like heat and sound, radiates in straight lines in all directions from its source. We can see this to be true by admitting rays

of light into a darkened room through small openings in the shutters, the rays making straight lines across the darkness, as may be seen by the motes which are flying in the air. The fact is recognized by the marksman in taking aim, and by the engineer in making his levels. The carpenter acts upon it when he tests the smoothness of any surface by letting the light pass along over it to his eye.

337. **Diffusion of Light.**—As light passes in all directions from any body or point, the farther we go from its source the less will the light be. If we take any two rays of light, the farther we trace them from their source the farther are they separated from each other, and what is true of any two rays is true of all the rays. It follows that the farther removed any surface is from a source of light the less light will there be upon it. This decrease of light in proportion to distance is a perfectly regular decrease, and it is as the square of the distance; or, in other words, the intensity of light is inversely as the square of the distance. Take a screen, Fig. 223, and a candle, placing a square piece of pasteboard between them at one foot from each. The shadow on the screen, you see, covers a space four times as large as the pasteboard.

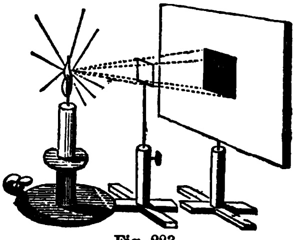


Fig. 223.

That is, the light that shines on the pasteboard, if allowed to pass on to the screen, would be diffused over four times the space, and therefore would have only one-quarter of the intensity. So if, as shown in Fig. 224,

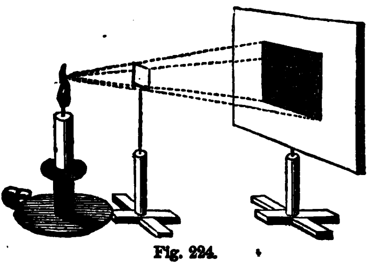


Fig. 224.

the screen be placed at twice the distance from the pasteboard that the light is, the shadow will cover a space nine times as large as the pasteboard, and therefore the light there would have one-ninth of the intensity which it has where the pasteboard is. Again, it is seen by Fig. 225 that if the screen be placed at the distance of three feet the intensity of the light is one-sixteenth of that which it is at the pasteboard. While the distances, therefore, are as 1, 2, 3, 4, etc., the intensity of the light is *inversely* as the numbers 1, 4, 9, 16, etc., that is *inversely as the squares of the distance.*

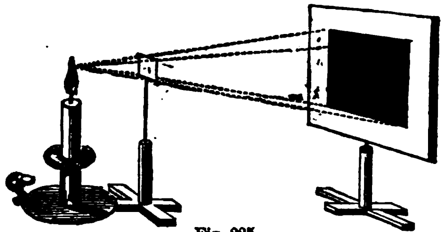


Fig. 225.

338. **Velocity of Light.**—The velocity of light is so great that within any ordinary distances it may be considered as instantaneous. Thus when we measure the distance of a cannon by the difference between the time of its flash and the report, we do not reckon the light to consume any time in its passage to the eye. But when we come to look at objects as distant as the sun and other heavenly bodies, we reckon in our calculations the time of the passage of light. It takes light eight minutes to travel from the sun to us, a distance of ninety-five millions of miles. With the telescope stars have been seen which have been ascertained to be at such a distance that it requires over ten years for their light to come to the earth. Others have been seen which are much farther off, but their distances have not been absolutely ascertained. Some have been seen supposed to be at such a distance that the light coming from them to the eye of the astronomer was a hundred thousand years in its passage.

339. **Roemer's Observations.**—The velocity of light

was first determined by Roemer, a Danish astronomer, in 1676. It was done in his calculations and observations of the eclipse of one of Jupiter's moons. After making the calculation of the time it would take for the satellite to pass through the shadow of the planet, he observed its passage, and found that it did not come out from the shadow as soon as his calculation required by fifteen seconds. What was the difficulty? If the earth had remained in one spot from the beginning to the end of the passage of the satellite, the observation would have come out exactly according to the calculation. But the earth had moved during this time (about forty-two hours and a half) the immense distance of 2,880,000 miles. The light of the emerging satellite therefore had to travel over this additional distance to overtake the earth, and it took fifteen seconds to do it. If we divide, then, this distance by 15 we get the distance which light travels in a second, which is 192,000 miles. All this can be made clear by the diagram, Fig. 226. Let S be the sun, J Jupiter, and C one of its moons emerging from its shadow. Let A be the earth as it is when the eclipse of Jupiter's moon begins. When it emerges the earth has passed to B, and the light from the satellite has to travel as much farther to reach it now as B C is longer than A C. Roemer made other observations with the earth at some other parts of her orbit with the same result.

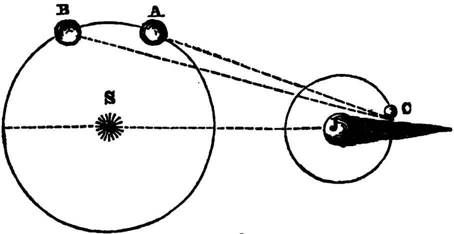


Fig. 226.

340. **Reflection of Light.**—Light, like sound and heat, is reflected in straight lines when it strikes upon any resisting substance. We can see this to be the case when

it strikes upon any smooth and plane surface. And it is true of light, as it is of heat, that the angles of incidence and reflection are equal. Thus if *c*, Fig. 227, be a reflecting surface, and *b c* a line perpendicular to it, then a ray of light, *d c*, will be reflected in the line *c a*, and the angle of incidence, *d c b*, will be equal to the angle of reflection, *b c a*.

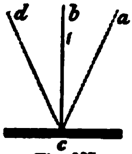


Fig. 227.

341. **How we See.**—We see the various objects around us by the light which is reflected from them. Every point of every surface that we see reflects rays or vibrations of light to our eyes. Thus if we see a person there are rays of light reflected into our eyes from every part of him. These rays form an image of him in the back part of each eye, and it is by this image that we see him, as will be explained in full in another part of this chapter. Reflected light is painting the images of objects in the eye every moment in great abundance and variety. If a speaker have an audience of a thousand persons all looking at him, his image is at the same time in two thousand eyes, and in each of these two thousand images every motion and every changing expression are faithfully depicted.

342. **Mirrors.**—That reflected light does thus form images of objects you see in the common mirror. The image formed in it of any object comes from the light reflected from that object into the glass. Then in seeing the image light is reflected from it into the eye, there to form a similar image, though of much less size. By using two or more mirrors the reflections of the image can be multiplied, and by some arrangements of them to a very great extent. That the image appears to be at the same distance beyond the surface that the object is before it, is owing to the fact that the reflected rays come from the glass at the same angle that the incident rays strike upon it. This may be shown from Fig. 228 (p. 263). Suppose *m m′* is a looking-glass, and an arrow, A B, is

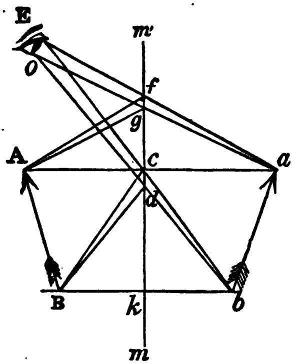


Fig. 228.

before it. Rays of light come from it at all points to the glass. We will take only two of these rays at each end of the arrow. The ray A *g* will be reflected to the eye at the same angle in the ray *g o*, and the ray A *f* will be reflected in the ray *f* E. And the reflected rays will have the same rate of divergence as the incident rays. The same can be shown in regard to rays from B or any other point on the arrow. Now if the lines *o g* and E *f* be extended, they will meet at the point *a*, which is at the same distance behind the mirror as A is before it. The same thing can be shown of the rays from B or any other point. Therefore the image of the arrow will appear to the eye to have the same relative position behind the glass that the arrow itself has before it.

343. **The Kaleidoscope.**—I have already noticed the multiplication of the images of objects by using two or more mirrors. In the kaleidoscope, by a particular arrangement of mirrors, the images are multiplied, and by changes in the position of the objects the relative positions of the images are infinitely varied. Fig. 229 will serve to explain the operation of the instrument. Let A B and B C be two plane mirrors placed at right angles to each other, and *a* an object before them. Let I be the

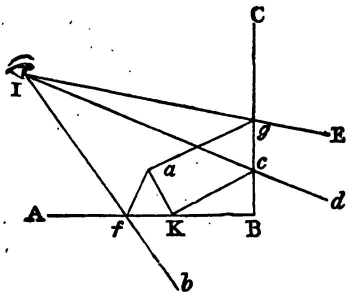


Fig. 229.

position of the eye looking at the mirrors. The rays *a f* and *a g* will be reflected to I as represented, and the eye will see two images, which appear to be at *b* and E. But the ray *a* K will be reflected to *c*, and then to I, so that a third image will be seen at *d*. Here is but a single second reflection, or reflection of an image; but by placing the mirrors at an angle of 60°, 45°, and 30° the images may be increased to six, eight, and ten, having a circular arrangement. In the kaleidoscope two mirrors are placed in a tube at an angle of 30°, and variously-colored pieces of glass in the farther end of the instrument, changing their relative position with every movement of it, give an endless variety of images symmetrically arranged.

344. **Curved Mirrors.**—These may be concave or convex. The action of a concave mirror upon light may be illustrated by Fig. 230. If parallel rays, as represented, strike upon the mirror they will, in their reflection, be made to *converge*, or come together, at the focus, *a*. But suppose the light comes from this focus, the rays of course *diverging*, or going away from each other; then the rays, as reflected, will be parallel. If the light or object be nearer to the mirror than the focus, and the rays of course be more diverging, then the effect of the mirror will be to lessen the divergency when the rays are reflected. You see that the tendency is to make the rays converge. And hence concave reflectors are much used when it is desired to throw a great amount of light in one direction. The effect of the concave mirror upon the apparent size and position of objects placed before it varies with the relation of their position to the focus. The action of a convex mirror upon light is the opposite of that of the concave. Its tendency is to make the rays diverge. Thus

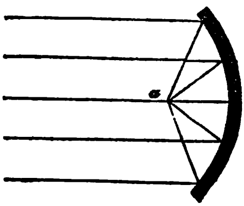


Fig. 230.

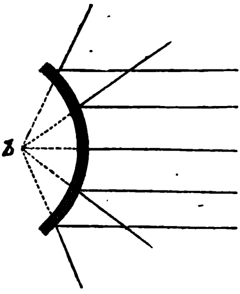


Fig. 231.

(Fig. 231), if parallel rays strike upon a convex mirror they diverge, as if they came from a focus behind the mirror, as *b*, as indicated by the dotted lines.

345. **Refraction of Light.** — When light passes from one medium into another it is bent from its course. This may be illustrated by Fig. 232, in which A B C D is a box, into which a candle, E, is shining. The candle is so placed that the shadow of the side A C falls at D.

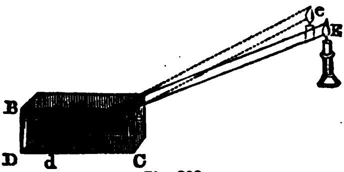


Fig. 232.

But let the box be filled with water, and now the shadow is removed to *d*, as if the candle were at *e*. This is because the rays of light from the candle, in passing from the air into the water, are bent or refracted so as to take a different direction. Here we have light passing from a rarer into a denser medium. Let us see now how it is when light passes from a denser medium into a rarer.

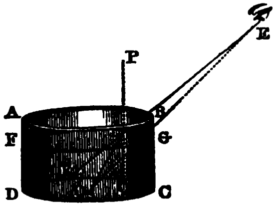


Fig. 233.

This can be illustrated on Fig. 233. Let the vessel, A B C D, be empty, and let a coin be placed at O. Let the eye, E, be in such a position that a straight line, O G E, from the coin to the eye would strike the side of the vessel a little below the edge, or, in other words, that the edge of the vessel would prevent the eye from seeing it. If now, keeping the eye in this position, water be poured in up to a certain level, say F G, the coin comes into view. This is because light coming

from the coin to L is bent into another direction, L E, and the coin therefore appears to the eye to be at K. In this case the refraction is *from* the perpendicular, P Q, let down through the point L, where the light emerges from the denser into the rarer medium. But when light passes from a rarer into a denser medium the refraction is reversed—it is *toward* the perpendicular. It is from this refraction of light that a stick partly immersed in water appears to the eye to be broken just at the surface of the water.

346. **Dawn and Twilight.**—The light of the sun, in passing from space into our atmosphere, is refracted. If it were not we should have no daylight preceding the rise of the sun, or twilight after its setting; but light would burst upon the darkness of night at once when the sun appeared above the horizon, and darkness would suddenly succeed to the light of day at sunset. As it is, in the morning the light bends toward us as it strikes across the atmosphere long before we see the sun, and after the sun has disappeared from view at evening its light bends toward us in the same manner. And farther, we really see the sun in the morning before it gets above the horizon, and in the evening after it has gone below it. This may be made clear by Fig. 234. Let the central ball represent the earth. Now as the atmosphere is most dense near the earth, and is rarer as you go outward from the earth, it is represented in the figure as

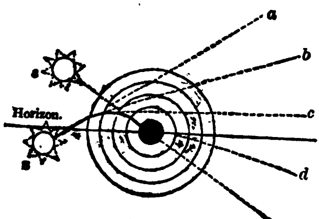


Fig. 234.

having different layers in order that the operation of the refraction may be more clear to you. The outermost layer is exceedingly rare, and each layer is more dense than the previous one as you go in toward the earth. The light coming from the sun, S, below the horizon into

the first layer of air, instead of passing on straight to *a*, as indicated by the dotted line, bends toward the earth. Then in entering the second layer, instead of passing on to *b*, it will be bent or refracted still more, as this layer is denser; and so on through all the layers, being refracted in each more than in the previous one. The result is, that as every object is seen in the direction in which the rays from it at length reach the eye, the sun, though really below the horizon, appears to be above it, as represented. The path of light from the sun, as it passes through the air, is a curved line. This is because the air, instead of being of uniform density, lessens in density as we go from the earth. If it were of uniform density the light would be refracted in straight lines, as in the experiments in § 345.

347. **Mirages.**—Sometimes inequalities occur in the density of the lower portions of the atmosphere, causing, of course, unequal refraction, and producing some strange appearances, termed *mirages*. For example, at Ramsgate, on the coast of England, there was seen, at one time, as represented in Fig. 235 (p. 268), a ship at such a distance that only her topsails were visible; and above in the air there were two complete images of the ship, the uppermost being erect and the under one inverted. Captain Scoresby, in a voyage to Greenland, saw an inverted image of a ship so well defined that he decided that it was the image of his father's ship, the *Fame*, which was afterward verified. The ship itself was at that time at a distance of 30 miles. An incident in the early history of the author's place of residence may be cited as an example of mirage. A ship left for England freighted with a valuable cargo, and having on board a large number of the best citizens of the colony. Some time after there was immense excitement in New Haven, because the inhabitants saw, with great distinctness, what they supposed to be this vessel, at only a little distance, apparently sailing against the wind. But it soon disappeared

Fig. 235.

from view, part after part, until the whole was gone. The ship itself was never heard from, and it was supposed at the time that this appearance was a manifestation of Providence for the purpose of informing the colonists what had become of their friends. But what was seen was undoubtedly the reflected image of this or some other ship. It is such appearances as these that have given rise to the stories which have been sometimes told of phantom ships. Mirages are very common in the extensive deserts in hot climates, exhibiting to the eye of the traveler various deceptive appearances, as islands, lakes, etc. In Bonaparte's campaign in Egypt such an appearance caused whole battalions of thirsty soldiers to rush forward, supposing at the moment that a plentiful supply of water was at hand.

The most astonishing instance of mirage of which I have ever heard is thus narrated: "The cliffs on the French coast are 50 miles distant from Hastings, on the

coast of Sussex, and they are actually hidden from the eye by the convexity of the earth; that is to say, a straight line drawn from Hastings to Calais or Boulogne would pass through the sea. A year or two ago, however, a Fellow of the Royal Society, who was residing at Hastings, was surprised to see a crowd of people running to the sea-side. Upon inquiry as to the cause of this he was informed that the coast of France could be seen by the naked eye. He immediately went down to the shore to witness so singular a sight, and there discovered distinctly the French cliffs extending for some leagues along the horizon, and so vividly that they appeared to be only a few miles off. The sailors and fishermen, with whom Mr. Latham walked along the water's edge, could hardly at first be persuaded of the reality of the appearance; but as the cliffs gradually became more elevated they were so convinced that they pointed out to Mr. Latham the different places they were accustomed to visit—such as the bay and the wind-mill at Boulogne, St. Vallery, and other places on the coast of Picardy, even as far as Dieppe, all the French shores appearing to the English sailors as if they were sailing at a short distance from them toward the harbors. With the aid of a telescope the French fishing-boats were plainly seen at anchor; and the different colors of the land upon the heights, together with the buildings, were perfectly discernible. The day when this occurred is said to have been extremely hot, without a breath of wind stirring, and the phenomenon continued visible in the highest splendor until past eight o'clock in the evening, having been seen for three hours continuously."

348. **Visual Angle.**—In order that you may understand the operation of lenses in relation to vision I must first explain to you what is meant by the visual angle. In Fig. 236 (p. 270) are represented arrows of the same size at different distances from the eye. From the ends of each of the arrows are drawn lines to the eye. The an-

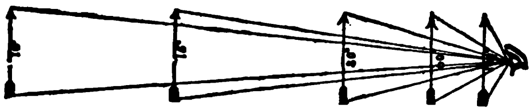


Fig. 236.

gle which these lines make in each case as they meet at the eye is termed the visual angle. Now the apparent size of an object depends upon the size of this angle. The degrees of the angles are marked upon the figure. Thus the visual angle of the nearest arrow is 120 degrees, and that of the second is 60, only half as large. The first arrow therefore appears twice as large as the second. For the same reason it appears four times as large as the third, eight times as large as the fourth, and twelve times as large as the fifth. The same thing is illustrated in another way in Fig. 237. Here the arrows *e f*, *g h*, and *i k* appear to the eye as large as A B, because they have the same visual angle, and for this reason make an image of the same size in the eye, as you see is indicated in the figure. It is hardly necessary to say that what is true of objects as a whole is true also of any part of them. Each part, however small, has its visual angle, and this governs its apparent size.

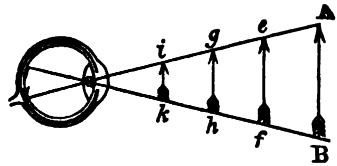


Fig. 237.

349. **Lenses.** — Transparent bodies having curved surfaces are called lenses. There are six kinds, represented in Fig. 238. The lenses in most common use are the double convex and double concave. The explanation of the mode in which these act upon light will sufficiently illus-

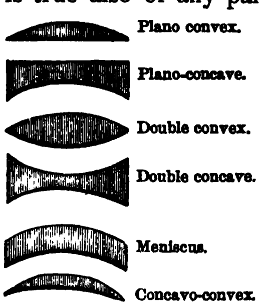


Fig. 238.

trate the operation of the others. They act by refraction, the convex collecting the rays, or bringing them nearer together, and the concave putting them farther apart. You can at once see, then, that a convex lens, by causing the rays coming from an object to converge more, increases the visual angle, and therefore makes the object to appear larger than it otherwise would. This effect is illustrated by Fig. 239. The rays of light coming from the arrow are made by the lens so to converge as to meet at *a*, instead of *b*, where they would meet if they did not pass through the lens. That is, by passing through the lens they have a larger visual angle, and therefore the object is magnified. The distance between *c* and *d* shows the size which the arrow would appear to have to the eye placed at *a*.

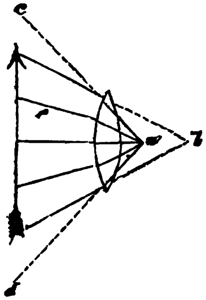


Fig. 239.

350. **Microscopes and Telescopes.**—What has been said of the action of the convex lens upon the visual angle will serve to explain the operation of the microscope. This instrument may be single or compound. The compound microscope has more than one lens, and is used to magnify very minute objects. Its operation may be seen by the diagram, Fig. 240. Rays from the object, E F, passing through the first lens, or object-glass, as it is called, form a magnified inverted image, G H, which is still more magnified by the eye-glass, C D.

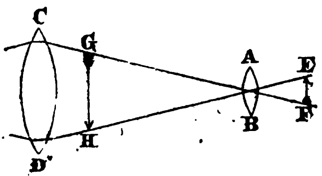


Fig. 240.

In the telescope we have also convex lenses, but they are arranged differently from those of the microscope, as the objects to be magnified are distant.

351. **Magic Lantern.**—This is an instrument by which

pictures made upon slips of glass with coloring substances which allow the light to pass readily are thrown upon a screen magnified. It is a metallic lantern, A A, Fig. 241, with a concave reflector, *p q*, and two convex

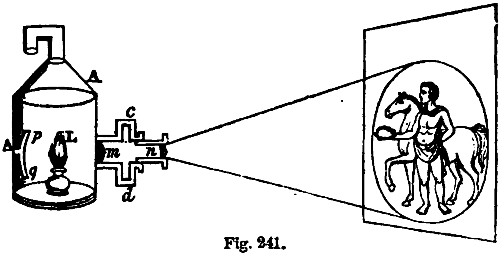


Fig. 241.

lenses, *m* and *n*. At *c d* is a space between the lenses into which the pictures are introduced. L is a strong light, which is in the focus both of the mirror and the lens *m*. The picture is therefore illuminated strongly by the rays reflected from the mirror and passed through the lens. The lens *n*, which is movable, is so adjusted as to throw a highly magnified image of the picture upon the screen. As the image is an inverted one the pictures must be inserted upside down, that the images on the screen may be upright. The *solar microscope* is, in its essential parts, like the magic lantern, the sun being used as the illuminator.

352. **Camera Obscura.**—This instrument differs from the magic lantern in giving us diminished images of objects. An instrument of this kind can be arranged extemporaneously any where. Thus, if into a darkened chamber light be admitted through a small opening, inverted images of any objects in front of the opening will be formed upon a white screen in the opposite part of the chamber. Such an arrangement is represented in Fig. 242 (p. 273), C D being the chamber, L the opening, and *a b* the image of the object A B. The images in such a case, however, are faint, because the opening must

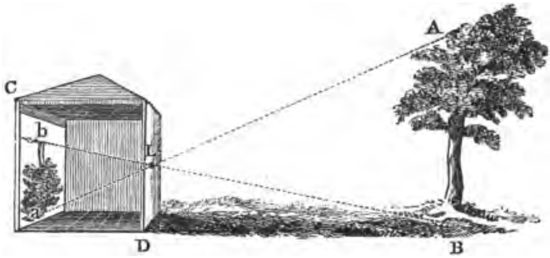


Fig. 242.

necessarily be small, and therefore but few rays, comparatively, come from the objects. By making the opening larger, and gathering the rays that enter it with a double convex lens, we can have well-defined and bright images of objects. Though the camera obscura may have various forms, I have described what is essentially the arrangement of the instrument. One form of it, for sketching either single objects or groups of them in landscapes, is represented in Fig. 243. Here the rays of light coming from objects strike upon a mirror, A B, and are reflected through a convex lens, C D, upon white paper on the bottom, E F, of the box, where the outlines of the images are traced by the sketcher. The light can enter only at the opening above, for on the side of the box which is open there hangs down a curtain on the back of the artist as he sketches.

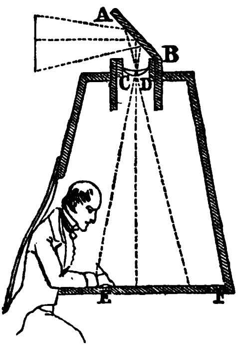


Fig. 243.

353. **The Eye.**—The eye is essentially a camera obscura. It is a dark chamber in which images are formed upon a screen in its back part, and the light which comes from objects is admitted through an opening in front,

where there is a double convex lens. That you may understand the manner in which the images are formed, I give you, in Fig. 244, a map of the eye. At *a* is the

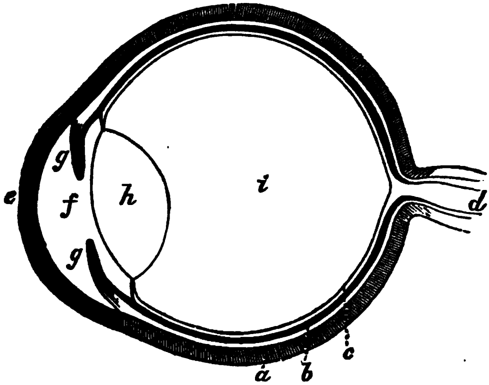


Fig. 244.

thick, strong white coat called the *sclerotic* coat, from a Greek word meaning hard. This, which is commonly called the white of the eye, gives to the eyeball its firmness. Into this is fastened in front, like a crystal in a watch-case, *e*, the *cornea*. The sclerotic and cornea, you see then, make together one coat of the eye, the outer one. The cornea is the clear, transparent window of the eye through which the light enters. Next to the sclerotic coat comes the *choroid* coat, which is dark, to prevent too much reflection back and forth in the eye. Then you have a very thin membrane, *c*, the *retina*, the screen on which the images are formed. This is composed chiefly of the fine fibres of the nerve of sight, *d*. To return to the front of the eye where the light enters—behind the cornea is the iris, *g g*, which is immersed in a watery fluid, *f*, called the *aqueous humor*. The light passing through the cornea and the aqueous humor comes to the crystalline lens, *h*, which, you see, is a double convex lens. Passing through this and through a jelly-like substance,

called the vitreous humor, which fills all that large space *i*, it strikes upon the retina, *c*, where it forms the images of the objects from which it came.

You see now how the eye is like a camera obscura. You have in it the dark chamber with its screen, the opening through the iris, the pupil, for the admission of the light, and just behind this opening the lens for gathering or concentrating the light before it falls upon the retina. The refraction of the light is not, however, done wholly by this lens. The projecting cornea, with its contained aqueous humor, refracts it considerably, for it forms a convex lens.

354. **Distinct Vision.**—In order that vision may be perfectly distinct, it is necessary that the rays coming from each point of the object which is seen should, on converging, meet together, or be brought to a focus on the screen of the eye, the retina. Thus, in Fig. 245, the rays which come from *a*, the end of the arrow, meet on the retina at *b*, and those from *c*, the other end, are brought to a focus at *d*.

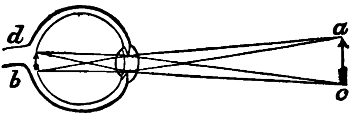


Fig. 245.

Now the muscles of the eye have considerable power in adjusting the eye to objects at different distances, so as to bring the rays in most cases together exactly at the retina. They fail to do it with objects that are very near. You can see that this is so if you bring any object, as your finger, nearer and nearer to the eye. You will at length find that you can not see it distinctly. The reason is, that the rays from it diverge so much that the cornea and lens can not make them converge enough to meet at the retina. This divergence of rays at different distances is illustrated in Fig. 246. Suppose that you

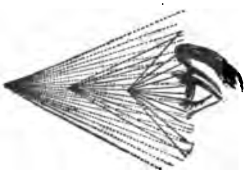


Fig. 246.

are looking at some very minute object. The nearer you bring it to the eye the better you can see it, till you come to a certain point. There the rays are so divergent, as you can readily see by the figure, that the lenses of the eye can not make them converge sufficiently for distinct vision. Now just here the microscope comes in to help the eye by causing these divergent rays to come nearer together before they enter the window of the eye, the cornea.

355. **Near-Sighted and Far-Sighted.**—Some persons have their eyes so shaped that they can not fully adjust them to objects at different distances. Thus the near-sighted can see with distinctness only objects that are near. The reason is that the rays converge too much, and are brought to a focus before they arrive at the retina, as represented in Fig. 247. The images therefore of distant objects are indistinct. If the retina could in any way be brought forward a little the difficulty would be obviated. But as this can not be done, concave glasses are resorted to, which counteract the effect of the too highly refractive power of the eye. In the far-sighted the difficulty is of an opposite character. The refractive power is so feeble that when near objects are viewed the rays are not brought to a focus soon enough, as seen in Fig. 248. Convex glasses are used in this case, making the divergent rays of near objects less divergent before they enter the cornea.

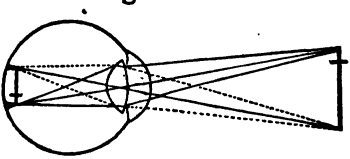


Fig. 247.

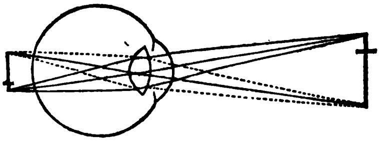


Fig. 248.

356. **Images in the Eye Inverted.**—The images formed on the retina are inverted. This can be proved by taking

the eye of an ox and carefully paring off the back of it, leaving little else than the retina itself. Holding now a candle before the eye, its image may be seen inverted upon its rear part. The question arises why it is that we see objects erect when their images on the retina are inverted. On this point I will quote from my *Human Physiology:* "It has been supposed by some that we really see every thing reversed, and that our experience with the sense of touch, in connection with that of vision, sets us right in this particular. And this it is supposed is the more readily done from the fact that our own limbs and bodies are reversed as pictured on the retina, as well as objects that are around us, so that every thing is *relatively* right in position. But if this be the true explanation, those who have their sight restored after having been blind from birth should at first see every thing wrong side up, and should be conscious of rectifying the error by looking at their own limbs and bodies. But this is not so. The above explanation of erect vision, and other explanations of a similar character, are based upon a wrong idea of the office which the nerve performs in the process of vision. It is not the image formed upon the retina which is transmitted to the brain, but an impression produced by that image. The mind does not look in upon the eye and see the image, but it receives an impression from it through the nerve; and this impression is so managed that the mind gets the right idea of the relative position of objects. Of the way in which this is done we know as little as we know of the nature of the impression itself."

357. **Single Vision.**—Whenever we see any object with both eyes there is an image formed in each eye, and impressions go from both eyes by the optic nerves to the brain. And yet with these two impressions there is no double vision so long as the two eyes correspond with each other in situation. This is because the image in one eye occupies the same place on the retina that the

image in the other eye does. The correspondence is ordinarily perfect, the two eyes turning always together in the same way, upward, downward, or laterally, without the least variation. You can observe the effect of a want of this correspondence by pressing one of the eyes in some direction with the finger while the other is left free to move in obedience to the muscles. When this is done every object appears double, because its image occupies in one eye a different part of the retina from what it does in the other, and so two different impressions are carried to the brain. The same thing occurs in squinting, in which the action of the muscles of the two eyes does not agree. Ordinarily in squinting there is not double vision, because the mind has the habit of disregarding the impressions that come from the defective eye. But when squinting occurs suddenly from disease there is double vision, for it takes a little time to form the habit referred to.

358. **Stereoscope.**—The images of objects in the two eyes, though always similar, are not generally perfectly alike. They are so only when the object presents a simple plane surface, as in the case of pictures. When the object presents two or more surfaces to the sight the images are more or less unlike. This can be illustrated in a very simple way. Hold a book up straight before your eyes with its back toward you. You see the back and both sides. Now if you shut your right eye you will see with the left the back of the book and the left side. That is, these two parts of the book are imaged on the retina of the left eye. By shutting the left eye it will appear that the image in the right is different, for you see now with the back the right side of the book. Here you have the explanation of the stereoscope. In the right side of this instrument you have the picture of the object as the object itself would appear to the right eye, and in the left side you have the picture of it as it would appear to the left eye. Thus, if a book in the po-

sition alluded to above were the object, in the right picture there should be represented the back together with the right side of the cover, and in the left the back with the left side of the cover. The two impressions, carried to the brain by the optic nerves, give together the impression of a solid book. The same principles apply to the representation of all solids in the stereoscope.

359. **Thaumatrope.**—Each impression made upon the optic nerve by light lasts about the eighth part of a second. No distinct impressions can be made, therefore, upon the retina unless they succeed each other with less rapidity than this. If, for example, in the revolution of a wheel, eight or more spokes pass by one point in a second, they can not be seen as distinct spokes, but will be mingled together, producing one continuous impression. So, too, if a light revolve so as to describe a circle in an eighth part of a second it will appear to the eye as one unbroken circle of light. It is this continuous impression on the retina that makes small objects, as the cars pass swiftly along, appear to run in long lines along with us. The fact thus developed is made use of in the contrivance of a toy called the thaumatrope. A picture is made on each side of a circular card, and whirling the card around very rapidly by means of two strings fastened to it, the two pictures are made to mingle together as one. Thus in Fig. 249 are represented the two sides of such a card, on the one side there being the picture of a dog, and on the other that of a monkey. When made to revolve rapidly the monkey will be seen sitting on the back of the dog.

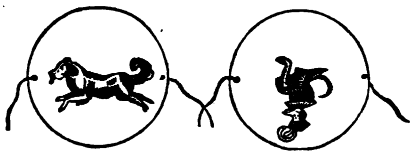


Fig. 249.

360. **Light Compound.**—I have thus far spoken of light as if it were a simple thing. But it is compound. Every

ray of white light has in it seven different colors. That this is so we can prove by taking a beam of light by itself and dissecting it, as we may say, or separating it into its seven parts. I will show you how this can be done. Let D E, Fig. 250, a beam of the sun's light,

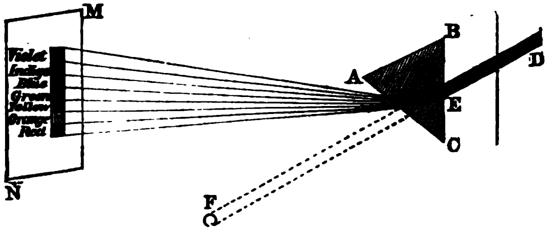


Fig. 250.

pass through a small opening in a shutter into a dark room. The rays will pursue a straight course, and if a screen be placed at F they will make a spot of white light. But if a glass prism, A B C, be held in the position represented the rays will be refracted, and when received upon the screen M N the light will be separated into seven colors in the order which is given. The figure thus produced is called the solar spectrum. Observe why it is that the colors are separated. It is because they are refracted unequally. If they were equally refracted the light upon the screen would be white, as before it was refracted. The violet rays are most refracted, the indigo next, the blue next, etc., and the red are the least refracted of all.

361. **Proportion of the Colors in Light.**—The colors in light are not equal in amount. If we divide the spectrum into 360 equal parts the proportion in the colors will be as follows: red, 45; orange, 27; yellow, 40; green, 60; blue, 60; indigo, 48; violet, 80.

Some suppose that there are really but three simple colors, red, yellow, and blue, the other colors being produced by a combination of these. Thus red and yellow

will together form orange, and yellow and blue will form green.

362. **Recomposition of Light.** — After decomposing light by passing it through a prism we can bring the separated colors together again and form from them white light. The manner in which this is done is represented in Fig. 251. The beam of light, after passing through the prism S A A′, instead of proceeding in the direction indicated by the dotted lines to form the spectrum, is made to pass through the prism S′ B B′, placed in a reversed position, and its rays are refracted so as to assume their original relation, making a white beam, M. Here the second prism counteracts the effect of the first, because its position is exactly the reverse.

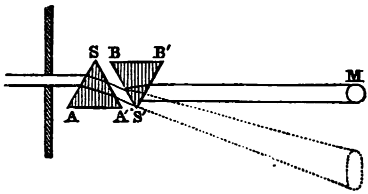


Fig. 251.

Newton very justly considered the decomposition and the recomposition of light as affording the most positive proof that white light contains all the seven colors. He tried various experiments to prove the same thing. Thus he mingled together intimately seven powders having the seven prismatic colors, and found that the mixture had a grayish-white aspect. He also painted a circular board with these colors, and found that on whirling it so rapidly that the colors could not be distinguished the whole board appeared to be white. In order to have this succeed perfectly the proportion between the colors must be observed, as in Fig. 252. A very pretty way of illustrating the composition of light is to have

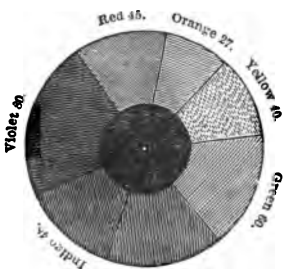


Fig. 252.

a top painted in this way. When the top is whirling rapidly it is white, but as it slackens its motion the seven colors appear.

363. **Colors of Objects.**—The color of any object depends upon the manner in which it reflects light. Thus, if it be red, it reflects the red rays of the spectrum, absorbing the other rays; and if it be green, it reflects the green rays, etc. If it reflect all the colors together, it is white; and if it reflect none, or almost none, of the light, it is black.

You can readily see why the color of an object varies with the kind of light that shines upon it. If an object which is red in sunlight be exposed to a yellow light, as a yellow flame, or sunlight that has passed through a yellow-colored glass or curtain, it loses its red color, for there are no red rays in the light to be reflected by it into our eyes. A person exposed to such a light has a deathlike paleness, the lips and skin losing entirely their red color. This effect can be witnessed at any time by mixing alcohol with a little salt on a plate and setting fire to it. You see in what has been said the reason that, in examining goods in the evening, especially by candle-light, we find the colors often differ somewhat from those which they have in the day.

In some substances the colors are changeable with varying positions, though the light be the same. We see this often in shells and minerals. We see it also in some fabrics, as changeable silk. This is owing to the arrangement of the particles, it being such as to occasion variety in reflection with changes of position.

364. **Colors of the Clouds.**—There is no more gorgeous display of colors than we sometimes see in the clouds at morning or evening, especially the latter. These colors are occasioned simply by refractions and reflections in the minute vesicles (§ 288) of which the clouds are composed. How simple are the materials, light, water, and air, and yet how grand and diversified are the results!

365. The Rainbow.—In producing the colors of the rainbow the materials are less even than in producing those of the clouds. They are only light and water. The colors come from the reflection and refraction of light in the drops of the falling rain. I will illustrate the manner in which these reflections and refractions take place. Take a single drop, represented in Fig. 253. Let S be a beam from the sun. This entering the drop at A, is refracted, and passes to B, at the farther side of the drop.

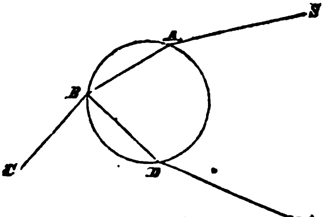


Fig. 253.

Here a portion of it is lost by its proceeding on in the line B C. The remainder is reflected to D, and passes to E, being refracted as it thus passes out into a rarer medium, the air. Here you have a single reflection and two refractions. But in the second bow, which is sometimes formed, there are two reflections as well as two refractions, as represented in Fig. 254. The beam of light, S, from the sun enters the drop at A, is refracted, and passes to B. Here a portion proceeds on in the direction B C.

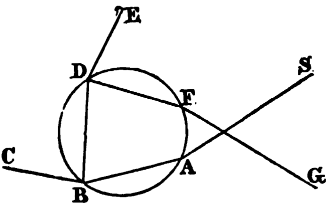


Fig. 254.

The other portion is reflected to D. Then this is lessened by a part of it proceeding on in the line D E. What remains is reflected to E. You see here the reason that the second bow is not so bright as the primary one. In the latter there is but one reflection in each drop, and therefore there is but one point where there is loss of light by its passing on out of the drop; while in the former there are two reflections, and therefore loss at two points.

366. Circumstances under which Rainbows are Seen. —A rainbow is seen when the spectator stands between the sun and falling rain. This commonly can not be the case except in the latter part of the day. It sometimes, though very rarely, happens that a shower passes from the east to the west in the morning, and then a rainbow can be seen in the west. Fig. 255 is intended to show

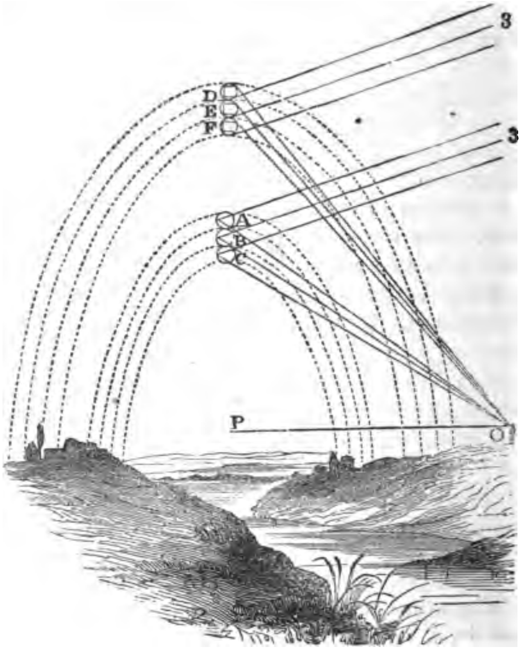


Fig. 255.

under what circumstances a rainbow is seen. Let a horizontal line be drawn from O, the observer, to P, a point directly under the middle point of the arch. If this line were extended backward from the observer it would be precisely in the direction of the sun from him. That is, the sun is directly opposite the middle of the

bow. Now if the drop at A reflect a red ray to the eye of the spectator all other drops similarly situated in the arch will reflect red rays. So if B reflect a green ray all other drops similarly situated will do the same. And so of C, reflecting the violet ray. For the sake of clearness there are only three reflections represented, but the same is true of all the seven colors. In the secondary bow the arrangement of the colors is reversed, the red being at the inner part of the bow and the violet at the outer part. The double reflections are manifest in the drops D, E, and F. What I have described as taking place in a few drops takes place in countless multitudes of them in forming the bow. As the exact place of the rainbow depends not only upon the direction of the rays of the sun but also the position of the spectator, it is clear that no two spectators see precisely the same bow, for the drops that form it for the one are not the same drops that form it for the other. This is very obvious if the two be quite distant from each other; but it is equally true if they are very near together, although in this case the bow for the one would be very nearly coincident with the bow for the other. It is also true that the rainbow of one moment is not the rainbow of the next, for as the drops that reflect it are falling drops there must be a constant succession of them in any part of the bow.

367. **Colors in Dew-Drops and Ice-Crystals.**—We often see something very analogous to the rainbow in the dew. As the sun rises, if, with our backs to it, we look at the dew-drops, we see all the colors of the rainbow glistening every where before us, as if the grass were filled with gems of every hue. Here we have the same refraction and reflection in drops of water, and the resemblance fails only in the regularity of arrangement which the rainbow presents. We see the same thing also if the ground is strewed with bits of ice which have fallen from the branches of the trees, and the sun shines aslant upon them.

368. **Heat and Light.**—We have not yet finished our dissection of the beam of light, begun in § 360. In the beam of light which is separated into the seven colors there is heat also; and in the separation it is found, as represented in Fig. 256, that the rays of heat are most abundant just beyond the red rays, while they are very sparing indeed at the other end of the spectrum. The greatest degree of light is at the boundary between the orange and the yellow rays.

Fig. 256.

369. **Chemistry of Light and the Daguerreotype.**—There is a chemical power also in light, producing every where, quietly but thoroughly, important effects. The chemical rays are most abundant at the end of the spectrum opposite to that where the heat-rays abound. It is these which do the work in Daguerreotyping. In this art light has been said to be the painter; but this is not strictly true. Light makes the image of the object, just as it does in the camera obscura and in the eye, but it has no power to fasten that image upon the metallic plate. This is done by the chemical rays, which, like the rays of heat, go along with the light. Without going into particulars, which will be given in Part Second, the process of Daguerreotyping is simply this: A metallic plate

is so prepared that the chemical rays of light shall act upon it sensibly. Then the object to be taken—a person or any thing else—being before the instrument, a slip of ground glass is inserted, and when the operator gets the lens so adjusted that a good image of the object is seen on the glass he takes this out and puts in its place the metallic plate. Rays of light coming from the object make the image, and the chemical rays bound up with the light act upon the plate so as to fix the image there.

CHAPTER XV.

ELECTRICITY.

370. **Origin of the Term.**—The ancients observed that when certain substances were rubbed together singular phenomena were produced. One of these substances was amber, and as the Greek name for this is ηλεκτρον, the power which is thus excited into action has been called electricity.

371. **Attraction and Repulsion in Electricity.**—One of the most common effects of electricity is attraction. If we rub a tube or rod of glass with woolen or silk it will attract light articles, such as cotton, feathers, lint, etc., so that they will adhere to it. But repulsion is also an effect of electricity under certain circumstances. In order that the explanation of these two opposite effects may be clear to you, I will detail some of the experiments which exhibit both. Suppose that we have a pith ball, A, Fig. 257, suspended by a silk thread, B, from a stand, C. I must premise that silk does not readily let electricity pass over it, or is a non-conductor, and therefore any electricity communicated to the pith ball will remain there unless

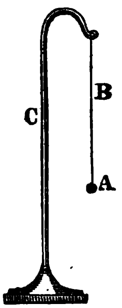


Fig. 257.

something be brought in contact with it or very near it. If now you rub a glass tube, thus exciting electricity upon it, and then bring it near the ball, it will attract the ball to it, and then in a moment repel it, so that it will stand off from the tube and retreat from it if you follow the ball with the tube. Why is this? It is supposed that there is a subtile fluid on the electrified glass, some of which passes to the ball as it touches the glass, so that the ball and the glass are in a similar condition. But the particles of the fluid repel each other; and this is the reason that the ball is repelled from the glass as soon as it becomes charged with a part of the electricity of the glass. For the same reason if two pith balls hanging from a standard become electrified from a glass tube or rod they will repel each other, for they are in the same electrical condition.

372. **Vitreous and Resinous Electricity.**—Suppose now that you rub a rod of sealing-wax with woolen or silk, and hold it near a pith ball which has been electrified from glass. It will attract the ball. The reason is that an electricity is excited on the sealing-wax of a different kind from that which is excited on the glass. The former is called *resinous*, and the latter *vitreous* electricity. They are supposed to be two fluids, which have a strong attraction for each other, while, on the other hand, the particles of either fluid are repellent to each other. It is this attraction between the two fluids which causes in the case just stated the sealing-wax to attract the ball to itself. We can illustrate this attraction in another way. Take two pith balls and electrify them, the one from glass and the other from sealing-wax. Brought near together they will attract each other, because they have two unlike electricities. This, you see, is just the reverse of the effect produced in an experiment cited at the conclusion of § 371, in which the electricities were alike in the two pith balls. Again, if you bring the rubbed sealing-wax near to the ball electrified from

glass, the ball will be attracted, and the same effect will follow if you bring the rubbed glass near to the ball electrified from sealing-wax.

373. **Franklin's Theory.**—In § 372 is developed the theory now commonly received in regard to electricity. The theory of Franklin was different. He supposed that there is but one electric fluid, and that all bodies are in their usual state charged with a certain portion of it, some having more than others, according to their capacity for electricity. While a body is in its usual state there is no manifestation of electricity. The fluid is in a quiescent condition, because its particles are prevented from repelling each other by the attraction which exists between them and the particles of the substance. But this quiescence can be disturbed by friction and other causes. Thus if a glass rod be rubbed with a piece of silk, the natural equilibrium is disturbed, the glass having an excess and the cloth a deficiency of electricity. The glass is therefore said to be *positively* and the cloth *negatively* electrified. The equilibrium can be restored in the case of a positively electrified body by having its excess drawn off, and in the case of a negatively electrified body by having its deficiency made up by receiving electricity from other bodies. Though this theory is discarded, the terms positive and negative derived from it are retained, being applied to the two fluids* or electricities, and they are often designated by the two signs + and —.

374. **Upon What the Kind of Electricity Excited Depends.**—It depends on what a substance is rubbed with whether vitreous or resinous electricity is excited in it. Thus smooth glass rubbed with woolen cloth or silk will be positively electrified; while if it be rubbed upon the back of a cat it will exhibit negative or resinous electricity. So, also, if a resin, as gumlac or sealing-wax,

* We are in entire ignorance of the nature of electricity, and we use the term *fluid* merely as a matter of convenience.

be rubbed with silk or woolen cloth, it will be charged with resinous electricity, but it will be charged with vitreous or positive if it be rubbed with sulphur. The terms vitreous and resinous are therefore incorrect, for they are based upon the idea that one kind of electricity is always excited on glass, whatever the friction may be made with, and that the other kind is always excited on resins. The most decided illustration of the incorrectness of these terms we have in the fact, that while smooth glass rubbed with silk or woolen cloth becomes charged with positive (vitreous) electricity, roughened glass rubbed with the same gives us negative (resinous) electricity. Below I give a table of substances, any one of which has positive electricity developed on it when it is rubbed with any substance below it on the list, and negative when rubbed with any substance above it:

1. Cat-skin.
2. Polished glass.
3. Woolen cloth.
4. Feathers.
5. Wood.
6. Paper.
7. Silk.
8. Sealing-wax.
9. Amber.
10. Roughened glass.
11. Sulphur.

375. **Conductors and Non-Conductors.**—Electricity passes over the surface of some substances very readily; while over others it moves with very great difficulty, and therefore very slowly and sparingly. The former are termed conductors, and the latter non-conductors. As in the case of heat, so with electricity there are no substances which are wholly non-conducting. The best of all the conductors are the metals, those least liable to oxydation being the most perfect. Next come charcoal, water, living substances, flame, smoke, steam. The best non-conductors are gumlac and gutta-percha. Then come amber, resins, sulphur, glass, silk, wool, hair, feathers, cotton, paper. Non-conductors are sometimes called *insulators*, from the Latin word *insula*, as they serve to confine electricity within certain bounds, and prevent its

escaping. Thus in the experiments with pith balls, already cited, the silk threads by which they are suspended prevent the electricity from escaping from them. So the glass knobs on which the wires of the telegraph rest are insulators, preventing the electric fluid from escaping down the poles into the ground.

376. **Electricity Always on the Surface.**—There is a marked difference between heat and electricity in the manner in which they are disposed of. Heat pervades all the particles of substances, and in its conduction spreads through them, while electricity in its ordinary movements operates altogether on the surface. A hollow ball, therefore, can contain as much electricity as a solid, and a hollow conductor of electricity is just as effectual as a solid one. The following experiment exhibits in a very striking manner this disposition of electricity to occupy the surface alone: Let *a*, Fig. 258, be a metallic ball supported by a glass stand, *b*; and let *c c* be metallic caps which will just cover the ball, having non-conducting handles, either glass or gumlac. Now, after having charged the ball with electricity, let the caps held by the insulating handles be carefully placed over the ball. On withdrawing them it will be found that the electricity of the ball has all passed to the outer surface of these caps.

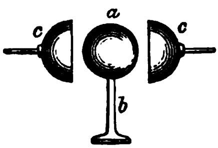


Fig. 258.

377. **Electrics and Non-Electrics.**—It will be observed, on looking over the list of conductors and non-conductors, that among the non-conductors are those substances in which electricity is easily excited by friction, such as glass, amber, silk, etc. These were therefore called electrics. The conductors, on the other hand, were called non-electrics, it being supposed that electricity could not be excited with them. But this has been found not to be true. For example, if a metal be insulated by being placed on a pillar of glass or of gumlac, so that

the electricity, when excited, can not pass off readily, its generation can be made manifest. It is probably true that every substance is more or less an electric, it being difficult to make this manifest in the case of conductors, because the electricity passes off as fast as it is generated.

378. **Electricity Every Where Active.**—I have said that there is electricity in all substances, each having its own capacity for it, but that in the usual condition of substances the electricity is in a state of equilibrium, and therefore of quiet. We see this quiet disturbed whenever there is a thunder-storm, when we rub glass or silk, or a cat's back, or when we work an electrical machine. But the active state of electricity is not limited to such palpable demonstrations as these. Electricity is undoubtedly in action every where and always, although we can seldom appreciate and measure its action. Wherever there is motion there is a disturbance of the equilibrium of electricity, and a consequent return to this equilibrium. And this change from the one state to the other must be the constant cause of important changes and operations in the world around us, and in our own bodies. Let us look at some of the indications of this universality of electrical action. The friction of any electric upon another awakens it. The friction of the belts upon the drums in cotton factories does it quite freely. Every stroke of India rubber upon paper as you erase a pencil mark excites electricity. The blowing of air upon glass does the same. So, also, does the blowing off of steam from an engine. Electricity has been excited even upon ice by rubbing it when cooled down to 13° below zero. Experiments upon the air have shown that there is usually some free electricity in it, the atmosphere being generally in a positive state, especially when the air is dry and clear. It is constantly generated from one source and another. It is generated every where by evaporation. Every gust of wind, causing friction of the particles of the air upon various substances, gener-

ates it. Motion of every kind probably generates it. Chemical action, as you will see in another part of this chapter, generates it every where. It is generated also in the operations of life, and in some animals there are special organs—electrical batteries—for the generation of this agent.

379. **Induction.**—A remarkable influence is exerted by an electrified body upon another body in its usual state when brought near it, and this influence is called induction. I will illustrate this by Fig. 259. Let A be a metallic ball standing on a glass pillar, and charged with positive electricity. Let B be a metallic cylinder supported upon two glass pillars. Now if A be placed near B, but not near enough for the electric spark to pass from it

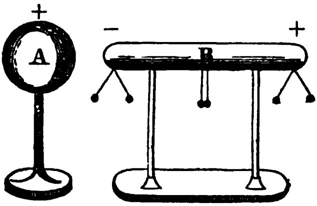


Fig. 259.

to B, it will destroy the equilibrium of the two electricities in B, the negative electricity being accumulated at the end near A, and the positive at the remote end. This is because the positive electricity in A repels its like in B and attracts the unlike fluid. You observe that there is a pair of pith balls suspended at each end of B, and also at the middle. The two balls at the positive end repel each other because they are charged with the same electricity, and so with the balls at the negative end. But the balls hanging from the middle are not affected, because they are on middle ground between the two electricities. Here is no communication of electricity from A to B, but only an influence upon the quiescent balanced electricities of B. Accordingly, if the surplus electricity of A be discharged by putting the hand or any good conductor upon it the influence will cease, the equilibrium in B will be restored, and the pith balls will all hang straight down. The same effect will be pro-

duced if A be withdrawn to a distance from B, and the influence will be renewed if A be brought near again.

If instead of one conductor we use two, B and C, Fig. 260, and have them in contact, we shall have the negative electricity on B and the positive on C. Now if we withdraw C from B we may have the two electricities separate, B being charged with the negative and C with the positive.

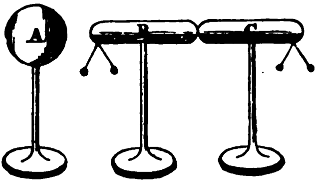


Fig. 260.

380. **Electrical Machine.**—You are now prepared to see how the common electrical machine operates. There are two kinds—the plate and the cylindrical. The plate machine, Fig. 261, has at *p* a large plate of glass, and at *r* a rubber which consists of two brass plates lined with leather which is stuffed, the pressure of which upon the glass is regulated by a screw. Above this rubber is a brass ball, *d*, and a brass chain connects the rubber and the ball with the floor, or, in other words, with the earth. At *c* is what is called the prime conductor—a hollow brass cylinder with rounded ends, having attached to it

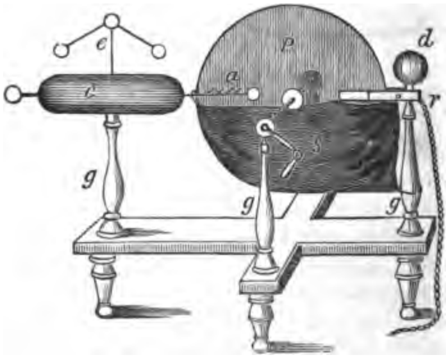


Fig. 261.

a rod with points, as seen at *a*. There is a similar rod attached to it on the other side of the glass plate. The different parts of the instrument are supported on glass pillars, *g g g*, standing on a wooden platform. The lower part of the plate is covered with a case of silk, which, being a non-conductor, prevents the electricity on the glass from being lost in the air, and also serves to keep the plate free from dust. The rubber is covered with an amalgam of tin, zinc, and mercury, this being found very effectual in exciting electricity. The operation of the machine is this: As the plate revolves positive electricity is collected upon the glass, and negative electricity upon the rubber. The former, as it comes to the points at *a*, goes to them and passes on by the rods to the prime conductor, while the latter passes from the rubber by the chain to the earth. The points at *a* are of great service in collecting the electricity, because the fluid is always much more ready to go to points than to conductors of a blunt shape.

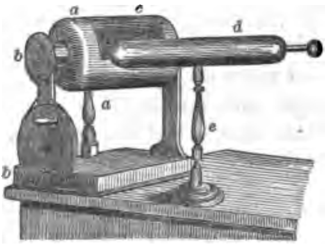


Fig. 262.

The cylinder machine is represented in Fig. 262, *a a* being a glass cylinder, which can be turned rapidly by the multiplying wheel, *b b*. At *c* is a piece of silk, and on the rear part of the cylinder is the rubber. At *d* is the prime conductor.

381. **Experiments.**—Many experiments may be tried with the electrical machine. I will cite a few of them:

If pith balls be attached to the prime conductor, as seen in Fig. 261, they will stand out from each other as soon as the machine is worked, because they are both charged with the same kind of electric fluid.

Let a small figure with its head covered with hair be placed upon the prime conductor. As soon as the con-

ductor becomes charged with electricity the hair stands out, as represented in Fig. 263, for the same reason that the pith balls diverged in the previous experiment.

Fig. 263.

Fig. 264.

So, also, if you place on the conductor a figure having attached to it strips of tissue-paper, they will diverge in the manner shown in Fig. 264.

Fig. 265.

Let a metallic plate, *a*, Fig. 265, be suspended by a chain to the prime conductor, and another plate, *b*, be supported upon a conducting stand. If figures of paper or pith be placed between these plates as the machine is worked they will move about briskly between the plates, being alternately attracted and repelled by the communication of the electricity.

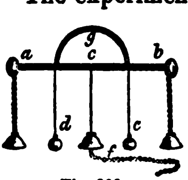


Fig. 266.

The experiment represented in Fig. 266 is a very beautiful one. Let *a b* be a brass rod with an arch, *g*, by which it can be suspended from the end of the prime conductor. To this rod are suspended three bells, the two outer ones by chains, and the middle one by a silk thread; also two clappers, *d* and *e*, by silk threads. The middle bell has a chain, *f*, connecting it with the table—that is, with the earth. The operation

of the apparatus is this: As soon as the outer bells become electrified they attract the clappers. These, on touching the bells, receive a portion of their electricity, and are repelled. They therefore strike against the middle bell, to which they impart the electricity which they received from the outer bells. They swing back again then in the same state that they were in at first, and now are attracted again by the outer bells. This goes on so long as the electricity is communicated.

Let there be pasted upon a slip of glass a continuous line of tin-foil, going back and forth, as represented in Fig. 267, and let there be a ball, G, connected with one end of the foil. The word light is made upon it by cutting out with a sharp knife little portions of the foil. If now with your finger on one end of the line of foil at *a*, you present the ball G to the prime conductor, the electric fluid will run along the whole length of the line from G to *a*. In doing this the letters are beautifully illuminated, a spark being produced at each interruption of the line. So rapid is the passage of the electricity that the whole appears to the eye simultaneously illuminated.

Fig. 267.

382. **The Insulating Stool.**—This consists of a wooden top, *a*, Fig. 268, supported by glass legs, *c c*. It can be made simply by boring holes in the four corners of a piece of board sufficiently large to admit the necks of bottles. Many amusing experiments can be tried with this. A person standing upon it can be highly charged with electricity by holding a chain connected with the prime conductor. The hair will rise up as represented in Fig. 263, and he can give electric shocks to other persons from any part of his body.

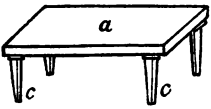


Fig. 268.

283. **Electricity Discharged from Points.**—I have already, in giving an account of the electrical machine,

spoken of the readiness with which electricity is received by points. It is discharged from them with equal readiness; so that, if a metallic point be attached to the prime conductor, the electricity will be carried off into the air nearly as fast as it is received upon the conductor. And as it passes off it creates a current in the air as it strikes upon it. The reaction of the air upon the electrical currents can be very prettily exhibited with the apparatus represented in Fig. 269, which consists of a cap, A, resting upon the point of a rod, and having pointed wires branching out from it in a wheel-like arrangement. You observe that the points are all bent one way. If this apparatus be set upright upon the prime conductor, the wheel can be made to revolve rapidly by working the machine. As the reaction of the air against the gases issuing from the rocket makes it rise, so the same reaction against the electricity issuing from these points causes the circular motion. If electricity be discharged from a point in a darkened room it appears like a brush of light, as represented in Fig. 270.

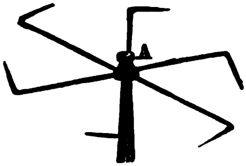


Fig. 269.


Fig. 270.


Fig. 271.

384. **Leyden Jar.**—The Leyden jar, Fig. 271, is so called because it was contrived at Leyden. It was suggested by an accidental result of an experiment tried there with the electrical machine. It consists of a glass jar coated upon the inside and the outside to near the top with tin-foil, and having a metallic rod passing through the cork, with one end touching the inner coating, and the other surmounted by a brass ball or knob. The jar is charged by holding the knob near to the prime conduct-

or while the machine is worked. The electricity passes by the metallic rod to the inside coating of the jar, and accumulates there. This is positive electricity. In the mean time there is an accumulation of negative electricity on the outside coating. But how is this? It is by the repulsion of positive electricity for itself, and its attraction for its opposite, negative electricity. As you hold the jar in your hand positive electricity is repulsed from its outside through your arm earthward, while negative electricity is attracted to it by the positive which is within. The two fluids get as near to each other as possible. They are prevented from coming actually together by the non-conducting quality of the glass. If a slip of tin-foil were made to connect the inside foil with the outer, there would be no accumulation of electricity on the inside, for as fast as it passed from the prime conductor to the inside it would pass out over the bridge of foil to the outside, and down your arm and body to the earth.

If there were no communication of the outside with the earth the jar would not be charged. No electricity would pass to it, because the positive electricity which is on the outside can not be driven off, and no negative electricity can be received. To make this plain, suppose that the jar, *a*, Fig. 272, having a bent rod, be suspended to the prime conductor, *b*. Here you have the inside tin-foil connected with the source of positive electricity. But the outside is insulated. No electricity can pass from it or to it. It has both positive and negative electricity, but they are in equilibrium. If there were a preponderance of negative electricity there, it would attract positive electricity to it as near as possible, and so the latter would enter the jar from the conductor. But there is no such preponderance, and so, though a little

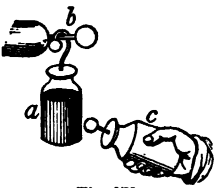


Fig. 272.

may enter—a spark or two—there will not be enough to charge the jar sensibly, because there is no attraction in that direction. But bring now another jar, *c*, near to the outside coating of *a*, and there is a movement at once in the electricities. The positive electricity has a chance now to pass off from the outside of *a* to the inside of *c*, leaving therefore a preponderance of negative electricity on the outside of *a*, which exerts an attractive influence on the positive electricity of the conductor drawing it to the inside of the jar.

385. **Discharge of the Leyden Jar.**—The jar may be discharged by making a communication between the inside and outside by means of any conductor. It may be done with the discharging-rod (Fig. 273). This has two slender metallic rods, with brass knobs at their ends, and jointed at *a*, so that the knobs can be separated to different distances. The handle is glass, so that as the electricity passes through the rods none of it may be communicated to the hand. In discharging the jar one knob is placed upon the outside foil, and the other is brought near to the knob of the jar.

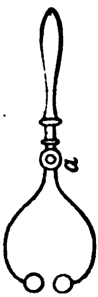


Fig. 273.

The two fluids now rush together from their attraction, and in doing so a bright flash is produced, going from the knob of the jar to that of the discharging-rod, and with this a report. You can yourself be the conductor to discharge the jar. If, having one hand upon the outside of the jar, you bring the other near its knob, the fluids meet in you as they do in the discharging-rod, and a shock will be experienced in proportion to the amount of charge in the jar. Any number of persons can together receive the same shock. To do this they must join hands, and the person at one end of the row must touch the knob of the jar while the person at the other end has his hand upon the outside.

You may touch either the knob of the jar or the out-

side coating *separately*, and the power that is in it remains quiet; but the moment that you touch both it bursts forth, because a bridge is made upon which the two fluids can meet.

In a dry air the charge in the jar can be retained for some time, the communication between the two electric fluids being very slow through the medium of air. It is otherwise when there is much moisture in the air, for water is a good conductor. For this reason, if you let the moisture from your breath come upon the jar between the outside coating and the rod, the jar will be discharged soon, though imperceptibly, the moisture making a medium of communication between the inner and outer electricities.

386. **The Electrical Sportsman.**—In this contrivance, Fig. 274, the discharge of the Leyden jar is very prettily exhibited. The jar, *c*, has a rod with two branches. On the end of one of these, B, are suspended pith balls cut in the shape of birds. On the other is a knob by which the jar can receive its charge from the prime conductor. After it is charged it is placed on the stand with its knob, *b*, near the gun, *a*, of a metallic figure. The suspended birds, you observe, stand out from each other, because they are charged with the same fluid, positive electricity, and therefore are repellent. Now when the chain, *e*, which is connected with the outside of the jar, is made to touch the foot of the metallic image, the connection between the inside and outside of the jar is established. Of course there is an instantaneous flash between *a* and *b*, and the birds, losing their

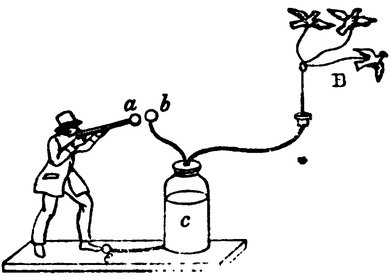


Fig. 274.

electricity, fall, and hang as they did before the jar was charged.

387. **Electrical Battery.**—By combining together a number of jars, having the insides all connected together, as seen in Fig. 275, with metallic rods, and the outsides connected together in a similar manner, we have what is termed an electrical battery. By such an arrangement we can accumulate a large amount of electricity, which can be discharged in the same way essentially as in the case of the single jar.

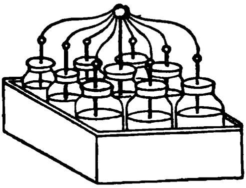


Fig. 275.

388. **Light of Electricity.**—The light produced by electricity is not occasioned by any thing like combustion. It depends obviously upon the resistance which is offered to its passage. Thus when the electric fluid passes through air from the prime conductor to the knob of the Leyden jar it causes a flash of light, but when it arrives at the knob the flash ceases. What is the reason of the difference? In both cases it has the resistance of the air, for when it comes to the knob it passes over the *surface* of the knob and rod; but in the latter case it is so diffused in its conduction over the metallic surface that it meets with much less resistance from the air. By experiments with the air-pump it is found that the denser the air is the more vivid is the spark; and if electricity be passed through a glass vessel from which the air has been mostly exhausted we have the streams of light seen in the aurora borealis, which are so strikingly in contrast with the vivid flashes of the lightning. In the experiment, § 381, in which the word light is made by the passing electricity, we have a striking illustration of the production of the spark by the resistance of the air. If the foil were one continuous surface the electricity would be diffused over it without giving any light. It is only where the electric fluid has to leap

through the air from one portion of foil to another that the light is seen.

389. **Sound of Electricity.**—The report of electricity is a sort of crack or snap from the sudden condensation of the air by the rapid passage of the fluid. The rolling of thunder is occasioned by the reverberation of the first sound among the clouds. The nearer the flash is to us the more like a crack is its first sound as it comes to our ears.

390. **Mechanical Injuries from Electricity.**—When any great amount of electricity meets in its passage with any imperfect conductor it does much violence to it. Thus it rends wood, scatters water, breaks glass, etc. Various experiments have been tried illustrating the manner in which mechanical injuries result from electricity. Thus if it be made to pass through a card or several leaves closely pressed together, there is a burr on each side of such a character as to show that two forces moving in opposite directions have made their passage.

391. **Heat Produced by Electricity.**—Electricity always produces in its passage some amount of heat, probably by its mechanical effect. When it is diffused over a large conducting surface the heat is not sufficient to be observable; but if it be confined to the surface of a small wire the heat may be sufficient to melt or even burn it. Various effects can be produced by the heat thus caused by the passage of electricity. Gunpowder may be exploded by it. Alcohol and ether may be readily ignited by it, especially the latter. Gas can sometimes be lighted by pointing the finger to an opened burner after walking across the room two or three times briskly, rubbing the feet upon a thick carpet.

392. **Franklin's Discovery.**—It had very early been conjectured that the electricity produced by the electrical machine is identical with lightning; but it was reserved for our countryman Franklin to prove the fact. A tall spire which was being erected in Philadelphia in

1752 he conceived might be used in his investigations, but before it was completed the sight of a boy's kite in the air suggested to him another plan. He made a kite by stretching a silk handkerchief over a frame, and sent it up as he saw a thunder-shower rising, his only companion being his son. Having raised the kite, he attached to the end of the hempen string a key, and also a silk ribbon, by which he insulated his apparatus, as seen in Fig. 276. He now watched with much anxiety the result. A cloud arose, which he supposed, from its appearance, was well charged with electricity, and yet no effect was

Fig. 276.

seen. Franklin began to despair; but he soon saw some loose fibres of the hempen string bristling up, and, applying his knuckle to the key, received just such a spark as he had often received from the conductor of an electrical machine. The discovery was made, and Franklin was at once overcome with emotion at the thought of the immortality which it would give his name. He felt very much as Archimedes did when, after making one of his grand discoveries as he lay in a bath, he went home saying all the way, Ευρηκα! Ευρηκα! The fame of the discovery, made in a manner so simple and yet so original, spread every where, and prompted to many experiments by other philosophers. One, Professor Richman of St. Petersburg, fell a victim to his investigations. While he was attending a meeting of the Academy of Sciences he heard the sound of distant thunder, and hastened home to make some observations with an apparatus which he had erected. While doing this a charge of electricity flashed from the conducting rod, and piercing his head killed him instantly. His assistant, who stood near, was struck down, and remained senseless for some time, and the door of the room was torn from its hinges.

393. **Lightning-Rods.**—It was the discovery of Franklin which led to the custom of attaching lightning-rods to buildings. The object of a lightning-rod is to conduct any electricity in a cloud that may come over the building down into the ground. For this purpose the rod should terminate in the air in points, as these, as you saw in § 380, so readily receive the electric fluid. The rod should be separated from the house by wooden supports, and it should pass so far into the ground as to have its end in the midst of continual moisture. The points should be gilt, in order to preserve from corrosion, or they may be made of silver or platina. Lightning is very apt to go down in chimneys, as smoke is a very good conductor; and therefore it is well to have

the rods go up by chimneys, especially if they are to have fire in them during the summer. Lightning-rods often undoubtedly are of service when there is no obvious passage of the lightning down them, by quietly and continuously receiving electricity upon their points, and passing it down into the earth.

394. **Galvanic or Voltaic Electricity.**—This form or mode of electricity I will barely notice here, reserving its full consideration for Part Second, where it appropriately belongs. The history of its discovery is interesting. The first dawning of Galvanism is to be found in an experiment noticed by Sulzer, a citizen of Berlin, in 1767. He states that if a piece of zinc be placed under the tongue, and a piece of silver upon it, on being brought in contact a metallic taste is perceived, and a shock is felt by the tongue. Sulzer attributed the effect to some vibratory motion occasioned by the contact of the metals, and, satisfied with this fanciful explanation, pursued the inquiry no farther. The statement excited but little notice until other facts of a similar character were brought out in 1790 by Galvani, professor of Anatomy at Bologna. He observed that the legs of some frogs, which had been obtained for his invalid wife, were convulsed, when near an excited electrical machine, on touching the nerves with a knife. In contrast with the example of Sulzer, he was led to examine the matter further. He found that the effect was produced when no electricity was communicated from the machine, by establishing a connection between the nerves and the muscles by some conductors. For example, when a strip of zinc was placed in contact with the nerve which goes to the lower extremities, and a strip of copper in contact with the legs, on bringing the two together at the other

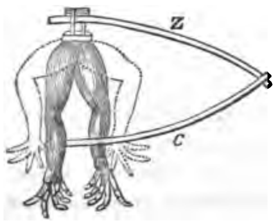


Fig. 277.

end the legs would be convulsed, being drawn up, as represented in Fig. 277 (p. 306). But Galvani did not get at the true explanation. He supposed this to be an exhibition of animal electricity, regarding the muscles as being a sort of Leyden jar, the nerve being the medium of communication with the inside.

395. **Volta's Pile.**—The observations of Galvani awakened much interest in all scientific minds, and of course there was much of inquiry, observation, and experiment. Professor Volta, of Pavia, went a step farther than Galvani toward the true explanation, in referring the effects to the contact of dissimilar metals, and he was led by this view of the subject to construct his *pile* or battery—called after him the voltaic pile—the object of which was to produce a much greater amount of electricity than could be obtained by the contact of only two pieces of metal. The pile is made of circular pieces of copper, zinc, and cloth, the cloth being moistened with salt-water. They are arranged as represented in Fig. 278. First a disk of copper is laid down, then upon this one of zinc, then one of cloth, and so on in the same order, the top of the pile ending in a plate of zinc. If you touch one end of the pile with a moistened finger and the other end with a finger of the other hand, you will feel a shock like that from a Leyden jar. The communication between the two ends of the pile may be made by wires, as seen in the figure. Volta afterward changed this to the form of a cup battery, the plates of metal being immersed in a series of cups in a mixture of sulphuric acid and water. There have been various improvements from time to time, but the arrangement is in all the different batteries essentially the same. Although Volta accomplished so much he did not arrive at the truth in full. His "contact theory," as it is called,

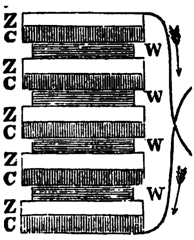


Fig. 278.

so long received as the true theory, gradually gave way to the true explanation, viz., that the electricity produced is owing to chemical action.

396. **Difference Between Frictional and Voltaic Electricity.**—The electricity produced by the friction of the electrical machine is more intense than that of the voltaic battery. Voltaic electricity, on the other hand, is much more abundant, and is more continuous and lasting. As it is therefore more steady and more easily controlled than frictional electricity, it is used in the working of the Telegraph.

CHAPTER XVI.

MAGNETISM.

397. **Loadstones.**—It was discovered many centuries ago that a certain ore of iron has the property of attracting pieces of common iron or of steel. The fact was probably considered at first as a mere curiosity, and the world were slow to find out its value. It is not till quite recently that it has been discovered that in magnetism we have one of the great forces of the earth; and even now we know but little probably of the real extent and variety of its action. New and important discoveries are yet undoubtedly to be made in regard to the agency and the laws of this mysterious power, and its connections with the other grand forces of nature. The terms magnet and magnetism come from the fact that the loadstone was first found near Magnesia, an ancient city in Asia Minor. This ore appears in considerable masses in the iron mines of Sweden and Norway, and also in different parts of Arabia, China, and Siam. It has occasionally been found in small quantities in England and in this country.

398. **Attraction of Magnetism.**—The attraction of the

magnet and iron for each other is exhibited in many different ways. If a magnet be brought near to a heap of iron-filings or needles, it will have a quantity of them adhering to it as you raise it up. In the toy fishes of children there is fastened in the head a bit of iron, which occasions the following of the fishes after the magnet. In this case you can see very plainly that the nearer the magnet and the iron are to each other the stronger is the attraction. Indeed, the attractive influence is governed by the same law in regard to distance as the common attraction of matter is, viz., it is inversely as the square of the distance. The attraction also is mutual here, the iron attracting the magnet as much as the magnet does the iron.

399. **Poles of the Magnet.**—Every magnet has two poles. It is about these poles where the chief power resides. For this reason, if a magnet be rolled in iron-filings, these are collected about the ends, as represented in Fig. 279. There is a diminution of attraction from the ends to the middle line, which is called the *neutral line*. These poles are called north and south poles, because if a magnet be suspended, or be supported upon a pivot, so that it can revolve, it will take a north and south direction, one of its ends invariably pointing toward the north. In Fig. 280 is represented a magnet supported upon a pivot, C.

Fig. 279.

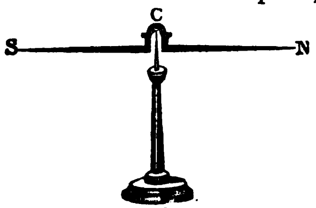


Fig. 280.

400. **Magnetism by Induction.**—The magnet in exerting its attraction really temporarily makes a magnet of what it attracts. Actual contact is not necessary to this result. Thus if a large key be only brought very near to a powerful magnet it will support small keys, as rep-

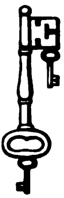


Fig. 281.

resented in Fig. 281. When the key is removed away from the magnet the keys attached to it fall. You see the analogy to the induction of electricity noticed in § 379. As in the induction of electricity, so here the two ends of the body in which the influence is induced are in opposite states. If the end of the magnet, to which the first key is near or attached, be the north pole, the end of the key next to the magnet is the south pole, and its farther end is the north pole. The same is the case with the small key attached to the end of the large one. And so if a nail should hang from the small key, and a needle from that, both of these would have the same polarities. But all this would be reversed if the large key were attached to the south pole of the magnet. In this case the upper end of each of these articles would be the north pole, and its lower end the south pole.

401. **Attraction and Repulsion in Magnets.**—You have seen in induction that in magnets *like poles repel while unlike attract.* But this law can be more strikingly illustrated. If a magnet be placed on a pivot, as in Fig. 280, and another magnet be brought near it, attraction or repulsion will be manifested according to the mode of presentation. If a north pole be presented to a north pole, or a south to a south, repulsion will be the result. But if a north pole be presented to a south, or a south to a north, then attraction will be manifested.

402. **Magnetic Curves.**—The polarity of magnetism causes a very singular arrangement of iron filings when gently agitated upon a sheet of paper over a magnet, as represented in Figure 282. The curves which you see have been supposed by some to be occasioned by the escape of some

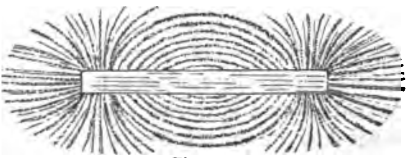


Fig. 282.

fluid or influence from the magnet in these particular directions. But they are owing entirely to the fact that each bit of filing is polarized by the bit next preceding it in the row reckoning from the magnet outward, the nearest one in each row deriving its magnetic state from the magnet itself. This being so, as the chief power resides in the ends of the magnet, it is easy to see how such a disposition of the lines of magnetic filings is effected. These curves may be beautifully and curiously varied by having several magnets variously arranged under the paper.

403. **Artificial Magnets.**—The power residing in the loadstone can be communicated readily, as you have seen, to iron and steel. Though soft iron takes the magnetic influence more readily than steel, it does not retain it as steel does, and the latter is therefore used in making artificial magnets. When a magnet imparts its magnetic influence it loses none of its own power, whether it be an original loadstone or an artificial magnet. There are many ways of imparting magnetism permanently to steel, but I will notice only two of them. If you wish to magnetize a bar or needle pass one pole of a magnet from one end of it to the other a considerable number of times, always in the same direction. A more effectual way is to take two magnets, and, placing the south pole of one and the north pole of the other in contact over the middle of the bar or needle, draw them slowly and steadily apart toward the opposite ends. This process must be repeated several times.

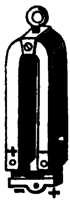


Fig. 283.

404. **Horseshoe Magnets.** — One of the most common forms of the magnet is the horseshoe magnet, Fig. 283. There is a piece of soft iron attached to the end of this, held there by attraction. This is called the *armature*. So long as it is suffered to remain there it is a magnet having its *two* poles, the north pole + being attached to the south pole — of the magnet which holds it,

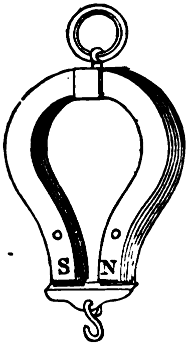


Fig. 284.

while the reverse is the case with its south pole. The object of the armature is to preserve the power of the instrument. Indeed it is found that the exertion of the magnet's power not only preserves but actually increases it. If you attach, therefore, to a magnet an armature having a hook, as seen in Fig. 284, you can add to the weight gradually from day to day, and so considerably augment the power of the magnet.

405. **Magnetic Needle.**—The magnetic needle is a very small magnet fixed upon a pivot. As it points north and south it is of great use to the mariner. The mariner's compass is a round box with such a needle balanced in it, and having a card on which is drawn a circle divided into thirty-two parts, as seen in Fig. 285. The original compass

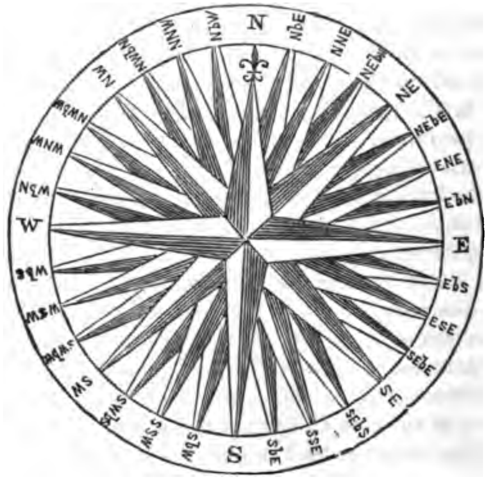


Fig. 285.

was a rude affair, consisting of a slip of loadstone laid upon a piece of cork floating in water. The date and place of its first use are unknown.

406. **Declination of the Needle.**—The declination of the needle is its deviation from a north and south line. It is in comparatively few parts of the earth's surface that there is no deviation from this line to the east or the west. "True as needle to the pole" has become a proverb, and when it was first uttered it was supposed to be founded in strict truth; but modern investigation has shown not only that the needle varies in its pointing in different localities, but that it varies to some little degree in its variations. The declination of the needle was first observed by Columbus in his first voyage of discovery, and it occasioned great alarm among the sailors, who, as Irving states, "thought the laws of nature were changing, and that the compass was about to lose its mysterious power." Notwithstanding these and other observations of a similar character, no great account was made of the declination of the needle till the middle of the seventeenth century. But since that time extensive records of its declinations at different localities have been made, and tables and charts have been constructed exhibiting them. These declinations are not constant, but vary somewhat every day, from the influence, it is supposed, of the sun upon the earth.

407. **Dip of the Needle.**—It is found that in most parts of the earth, if a needle be balanced before it is magnetized, and then be suspended from the same point, it will not be balanced, but one end will dip downward. This fact was discovered by Norman, a London optician, in 1576. He found that the dip at London was toward the north at an angle of 72°. In pursuing the investigation of this phenomenon it was found that going from the north toward the equator the dip constantly lessened, until a point was reached where the needle was horizontal. Then, on going south of this, a reverse dip oc-

curred, that of the south pole, and the farther south the needle was carried the greater was the dip. In the north, Captain Ross in 1832 came to a locality north of Hudson's Bay, in lat. 70° 5′ N., long. 96° 45′ W., where the magnetic needle, freely suspended, was in a vertical line. No such locality has yet been discovered toward the south pole.

408. **The Earth a Magnet.**—You can readily see, from all that has been stated in regard to the magnetic needle, that the earth is a magnet, or has that covered up in it which in some way acts as such. The dip of the needle shows that the two poles of this magnet are somewhere near the north and south poles of the earth. The locality which Captain Ross found must be near the north pole of the magnet in that quarter of the world. The vertical position of the needle there is analogous to the straight lines of iron filings which you see in Fig. 282, near the poles of the magnet; and it is easy also to trace the analogy between the dip of the needle at different distances from what is called the magnetic equator of the earth, where the needle is horizontal, and the curves which you see extending from pole to pole. The different declinations of the needle and the different intensities of the magnetic force in different localities corresponding in latitude show that the magnet in the earth, if there be one, is irregular in shape, or in some way has its power varied much in different parts of the earth's crust.

409. **The Earth as a Magnetizer.**—As the earth is really a magnet, it might be expected to impart magnetism by induction as other magnets do. And this is found to be the fact. If you hold a bar of soft iron in the direction of the dip of the needle it becomes a magnet, its lower end being the north pole, and its upper the south. That this is so can be ascertained by bringing a small magnetic needle near each end. No effect of this kind is produced when the bar is held horizontally east and

west. Lightning-rods, pokers, upright iron bars in fences, etc., are often found to be magnetized because they have continued so long nearly in the required position for magnetization. When a bar of iron has been magnetized in the manner indicated, its magnetism may sometimes be fixed by giving it a stroke with a hammer. It is a curious but inexplicable fact that this vibration of the particles of the iron should have this effect. But though such vibration helps to impart magnetism, it is not at all favorable to its retention, for magnets are always injured by blows or falls, or indeed any rude treatment. For this reason care is requisite in removing an armature from a magnet. If pulled off abruptly the power of the magnet is lessened.

410. **Magnetism in Other Substances besides Iron.**—It was formerly supposed that magnetism was confined to ferruginous substances, but this has been found not to be true. Various minerals are magnetic, especially when they have been heated, also some of the precious stones, and even silica, which enters so largely into some of the rocks of the earth. And it is supposed by some that future investigations will show that the influence of magnetism is as extensive in the earth as that of electricity.

411. **In what Magnetism is Like Electricity.**—Magnetism is like electricity in several particulars: 1. Its power is on the surface of bodies. 2. It is of two kinds, north and south, or boreal and austral, comparing with the positive and negative electricities. 3. The same rule of attraction and repulsion applies to both; viz., like repel and unlike attract. 4. As electricity can be communicated by induction, so can magnetism.

412. **In what Magnetism is Unlike Electricity.**—The circumstances in which magnetism is unlike electricity are chiefly these: 1. The obvious manifestations of magnetism are to a great extent confined to one class of substances, the ferruginous, and to but a portion of them; while electricity makes its manifestations in connection

with all kinds of substances. 2. Magnetism is never transferred as electricity is from one body to another, but a body gains rather than loses in imparting magnetic power to other bodies. 3. The two magnetisms, the boreal and austral, can not be obtained separately as the two electricities can. If a magnet be broken in two, each piece will have in it the two magnetisms and the two poles as the whole did. This is in entire contrast with the electrical experiment noticed in the last of § 379. 4. There are no non-conductors to interrupt magnetic influence. If in the experiments in § 379 a plate of glass or resin were interposed between A and B, the influence would cease, but it would have no effect on the induction of magnetism if interposed between a magnet and a bit of steel or iron.

413. **Electro-Magnetism.**—Though electricity and magnetism differ so much from each other, yet they have intimate relations, and it is now the general opinion among scientific men that they are merely different modes of the same power. Magnetism can produce electricity, and electricity can produce magnetism. The first discovery of facts revealing this connection was made by Professor Oersted of Copenhagen in 1819. Since that time electro-magnetism, or the production of magnetism by electricity, has been a prominent subject of observation and experiment. Oersted's first observation was that a current of electricity passing over a wire near a magnetic needle affected the position of the needle. He found also that iron filings would adhere to a wire over which a current of electricity is passing, just as they do to a magnet, dropping off, however, as soon as the current ceases to pass. Such facts led to a great variety of investigations and arrangements of apparatus by Oersted and others.

414. **Electro-Magnets.**—The most powerful electro-magnets are made by bending a thick cylindrical bar of soft iron into the form of a horseshoe, A B, Fig. 286, and

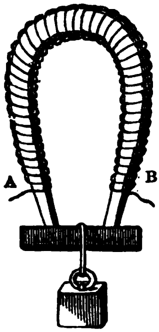


Fig. 286.

coiling around it a copper wire. The wire must be insulated by being wound with some non-conducting material, as silk, so that the electric current may pass through the whole length of the wire. With the instrument thus prepared, if the two ends of the wire be connected with the poles of a voltaic battery which is in action, the bar will be magnetized, and will hold up a heavy weight so long as the electric current is passing through the wire. Whenever the current is cut off by disconnecting the wires the weight will fall. Electro-magnets have been made in this way having such power as to sustain a weight of four thousand pounds. In Fig. 287 we have represented an apparatus which exhibits electro-magnetism very prettily. The soft iron, you see, is in two pieces, which when put together form a ring, *d*, and each piece has a handle. If the pieces be put together with the coil, *c*, in the position represented, on connecting the wires P and N with a battery in action, the adhesion is so strong as to resist a great force; but as soon as the connection is broken the pieces come apart at once.

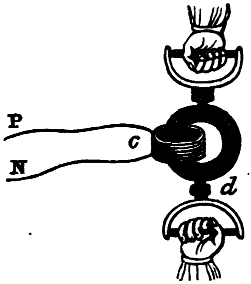


Fig. 287.

415. **Electric Telegraph.**—The most remarkable and useful application of electro-magnetism we have in the electric telegraph. As before stated, voltaic electricity is used. This is generated at the place from which the message is sent, and passes over the wire to the place where the message is received. There it acts upon soft iron by passing through coiled wire, producing the modified power called electro-magnetism. I will make all this

plain to you by describing the machine used in Morse's Telegraph, Fig. 288. W W are the wires which connect

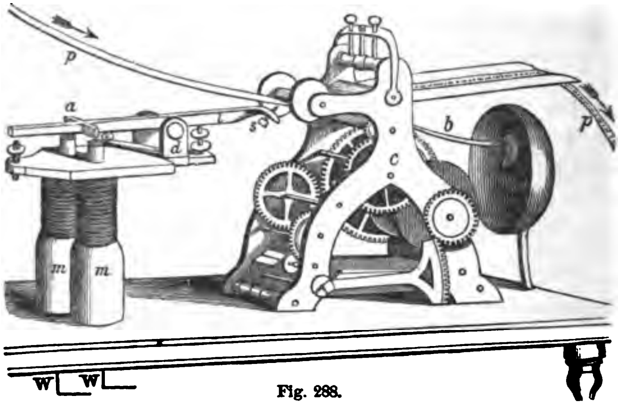


Fig. 288.

with the station from which the message is to be received, and these connect with the copper wire coiled round the horseshoe of soft iron, *m m*. Above the magnet is a lever, *a l*, which works on a fulcrum at *d*. One end of this lever has a steel point, *s*, attached to it. At *c* is an arrangement of wheel-work, the object of which is to pass along regularly a slip of paper, *p*, in the direction of the arrows. Observe now how the apparatus works. When the electric current passes through the coiled copper wire it makes a magnet of the iron, *m m*. The lever, *a l*, is therefore attracted at the end, *a*, downward. Of course the end, *l*, moves upward, bringing the steel point, *s*, against the paper, where it makes a mark. The length of this mark depends upon the length of time the electricity is allowed to pass along the coiled wire, for the moment that it is shut off *m m* ceases to be magnetic, the "keeper," *a*, being no longer attracted, moves upward, and the other end, *l*, of the lever moves downward, taking the point, *s*, from the paper.

In order to make the marks on the paper of different

lengths, there is a contrivance for regulating the length of time that the current shall pass through the coiled wire. This contrivance, called the *signal key*, is represented in Fig. 289. N and P are two strips of brass connected with the two wires R and M, of which M comes from the battery. The end of the strip N is raised a little above the end of P. So long as they do not touch the circuit is not complete, and no electricity passes. But if the operator press N down upon P, the circuit is established, and the electricity passes to the station with which he is in communication, and there acts upon the apparatus seen in Fig. 287. Now the longer the finger presses down N upon P the longer will be the mark on the paper at the distant station. An operator then at New York, for example, controls by this key the length of the marks made on the paper in New Haven or any other place with which he is communicating.

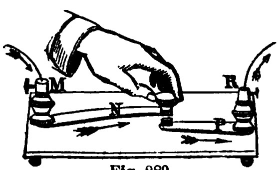


Fig. 289.

You can see then very readily how a telegraphic alphabet can be constructed by combinations of marks of different lengths agreed upon to represent different letters and numerals. I give the alphabet used in connection with Morse's Telegraph:

A	– —	N	— –		Numerals.
B	— – – –	O	– –	1	– — — –
C	– – –	P	– – – – –	2	– – — – –
D	— – –	Q	– – — –	3	– – – — –
E	–	R	– – –	4	– – – – —
F	– — –	S	– – –	5	— — —
G	— — –	T	—	6	– – – – – –
H	– – – –	U	– – —	7	— — – –
I	– –	V	– – – —	8	— – – – –
J	— – — –	W	– — —	9	— – – —
K	— – —	X	– — – –	0	————
L	———	Y	– – – –		
M	— —	Z	– – – –		

One of the most singular and interesting things in the operation of the telegraph remains to be noticed. In

order to have the electricity work it is necessary to have the connection between the poles of the battery at the point where the effect is to be produced. You see this in the experiments represented in Figs. 286 and 287. The same is true of the electro-magnet of the telegraph. This being so, it was thought at first that it was necessary to have two wires connecting two communicating stations; but it was found that only one wire was needed, the earth itself answering the same purpose as another wire. To make the communication through the earth effectual, there is at each station a plate of metal, having a surface of several square feet, buried in the ground, with a wire running up to the machine.

QUESTIONS.

[TEACHERS differ much in their plans of conducting recitations. Some are very minute in their questions; while others go to the other extreme, and merely name the topics, the pupils being expected to give in full what is said upon them. Neither of these plans should be adopted exclusively, but the mode of recitation should be much varied from time to time. This variety is somewhat aimed at in the questions which I have prepared, though in no case are the questions as minute as they should occasionally be made by the teacher. The numbers refer to the pages.

It would be well to have the pupils draw many of the figures upon the blackboard, and then recite from them. By drawing the simplest figures first sufficient skill may be acquired to enable the pupil to draw those which are quite difficult.]

CHAPTER I.

13. What is said of the distinction between matter and spirit? What of Bishop Berkeley's ideas? What of Hume's?

14. What is the origin of the word spirit? What is the relation of the senses to the spirit? What is said of the effects of matter on the senses? What are the forms of matter?

15. Illustrate the difference between elastic and non-elastic fluids. What is said of the union of the particles of a solid? Give the difference noted between different solids. How does a liquid differ from a solid? Give particularly what is said of water.

16. What is said of the particles of gaseous substances? What of the atmosphere? What of the vapor in it? What is said of the entering of liquids and gases into interstices? What of the mingling of gases with liquids? Give the illustration in regard to fishes.

17. What is said of the solution of solids in liquids? What of the evaporation of water in the air? Illustrate the influence of heat on the forms of matter. What is said of the thermometer? What of mercury, water, and iron in relation to the liquid state? What is said of our knowledge of matter?

18. What was the supposition of Newton about the composition of matter? What is said of the changes of matter? What are the imponderable agents, and why are they so called?

CHAPTER II.

19. What is said of variety in the properties of matter? What of the divisibility of matter?

20. What is said of gold-leaf, and of the wire of gold-lace? What

of the soap-bubble? What of the thread of the silk-worm, and of the web of the spider? What of solution of blue vitriol? What of odors?

21. What is said of the dust of the puff-ball? What of pollen? What of the dust rubbed from a moth's wing? What of guano? What of the glazing of visiting-cards? What of the minuteness of some animals?

22. What is said of the Deity in relation to minute animals? What is said of substances called porous? What of those in which there are no pores apparent? What proof is there that all substances have spaces in them?

23. What is said of the amount of space in gases and vapors? Give the statement in regard to steam. What is said of solutions of solids in fluids? What of evaporation? What of the diffusion of odors in the air?

24. What is the relation of heat to space in matter? Upon what do density and rarity depend? Explain tenacity. What is said of this property in gases and liquids?

25. How is the comparative tenacity of substances ascertained? Give the comparative tenacity of various substances. What animal substances have great tenacity? What is said of the value of tenacious substances?

26. What is said of hardness? What of flexibility and brittleness?

27. Give examples of flexible and brittle steel. Explain the actual difference between them. Explain the tempering of steel.

28. What is said of the annealing of glass? What of Prince Rupert's drops? What metals are the most malleable? What the most ductile?

29. What is said of the ductility of melted glass? What of the change of position of particles in making plates and wires of metals? What of welding? What is said of compressibility? What of the incompressibility of liquids?

30. What influence has heat on the bulk of liquids? Illustrate by the thermometer. What is said of the compressibility of gases? How does elasticity operate in the case of the India-rubber ball?

31. Give the illustration in regard to jumping. State the experiment with the ivory ball. What is said of the movements of particles on each other in elastic substances? What of the degrees of elasticity in different substances?

32. What is the definition of elasticity? What is said of the usefulness of the variety of properties in matter?

CHAPTER III.

33. What is meant by extension as a property of matter? Illustrate the fact that it is an *essential* quality. What is said of it in reference to air?

34. Does matter ever penetrate matter? Give the illustration represented in Fig. 6. Give that represented in Fig. 7.

35. State the arrangement of the diving-bell. Give the comparison between bullets and needles in relation to penetration. What is said of solution? What of odors?

36. What is the property of matter called inertia? Give illustrations of it. Illustrate the fact that matter has no power to stop its own motion. What is the reason that the popular notion is that matter is more inclined to rest than to motion?

37. What is said of perpetual motion? Why is it not true of divisibility that it is an essential property of matter? What is said of weight?

CHAPTER IV.

38. What is said of the nature of attraction? What was Newton's idea of it?

39. What is said of attraction in solids? What of its different modes of action? What is the difference in attraction in the case of steel and of water? What is said of the freeness with which particles of a fluid move among each other?

40. Explain Fig. 9. Explain Fig. 10.

41. Give the difference between mercury and water in regard to the globular form. What is said of drops of water on leaves?

42. What is said of oil in reference to attraction? Describe and explain the manufacture of shot. What is said of the globular form of the earth and the heavenly bodies?

43. What is said of crystallization? State the examples cited. What is said of the crystallization of water? Give and explain the example of sudden crystallization.

44. What is said of frost-work? What of snow?

45. What is stated in regard to the snow-crystals of the arctic regions? What is said of order in nature? Why can you not make the surfaces of broken glass adhere?

46. Explain the cementing of glass. What is said of the adhesion of pieces of India-rubber? Describe and explain the experiment with bullets and with balls of lead. How may silver and gold be made to adhere to iron? What is said of the adhesion of tin and lead? What of the adhesion of panes of glass?

47. Upon what does the strength of adhesion depend? Illustrate the agency of heat in promoting adhesion. Give familiar examples of attraction between solids and liquids. Explain the experiment represented in Fig. 15.

48. What is said of stems in stagnant water? Explain Figs. 16, 17, and 18.

49. Explain Fig. 19. Explain the rise of fluids in tubes by Fig. 20.

50. What is meant by *capillary* attraction? Give familiar examples of the rising of liquids in interstices.

51. Describe and explain the process of getting out millstones. How does a blotter differ from writing-paper?

CHAPTER V.

51. What is the attraction of *cohesion?* Give examples of attraction between masses or portions of matter.

52. Explain the falling of a stone to the ground. Illustrate the fact that attraction is mutual. Give the illustration of the ship and boat in full.

53. Illustrate the proportion between the mutual motions of the attracting bodies. Give the calculation in regard to the motion of the earth in attracting smaller bodies.

54. What is said of the universality of attraction? Explain the tides. What is said of the attraction of the moon for the land? What is the difference between the attraction of cohesion and the attraction of gravitation? Why is the word gravitation thus used? What is terrestrial gravitation?

55. Explain Fig. 22. Explain Fig. 23. What is said of substances suspended in different parts of the earth?

56. Explain Fig. 24. What is said of plumb-lines?

57. What is weight? Give the comparison in regard to muscular force. What is said of scales and weights? What of using springs in weighing?

58. What would be the effect on weight if the density of the earth were increased? In what ways would this be perceived? What is said of the variation of weight with distance?

59. What is said of the difference of weight on mountains and in valleys? What of weight in the moon? What of it in the sun? What is said of the different modes of attraction?

60. Show why attraction of cohesion *seems* to be different from gravitation. Show now that it is really not different. What is said of the experiment with the two bullets mentioned in § 66? What of the adhesion of liquids to solid substances?

61. What is said of the various results of attraction? Explain fully why you can pour water from a pitcher easier than from a tumbler.

62. Explain the operation of the quick movement by which you prevent water from running down the side of a tumbler in pouring it out. What is said of dropping from a vial? How is the size of drops limited? What is said of the movements of drops on window panes?

63. Why are the drops of different liquids different in size? Give the illustration about chalk. Give that about dust. Explain Figs. 27 and 28.

64. Explain Fig. 29. What is said of the difference in size between water and land animals?

65. Give the illustration in regard to trees. Give that in regard to mountains. What is said of the mountains of the moon? What of those of Jupiter? Give the illustrations in § 93 of transgression of the principles which have been elucidated.

66. What is the difference between the attraction treated of in natural philosophy and chemical attraction?

CHAPTER VI.

67. Show what we mean by the centre of gravity by Figs. 30, 31, and 32.

68. Give the definition of centre of gravity, and explain it. What is shown by Fig. 33?

69. How can we find the centre of gravity of a body? What is said of scales and steelyards?

70. State what is represented by Fig. 38. Illustrate the fact that the centre of gravity seeks always the lowest point.

71. Give the illustrations of the rocking-horse, the swing, etc. What is said of the Laggan stones? Why does an egg lie on its side?

72. Give the illustrations from toys in § 101. Give the illustrations in § 102.

73. Upon what two things does the stability of a body depend?

74. What is said of the stability of bodies whose shapes are represented in Figs. 48, 49, and 50? What of that of a round ball? Why is the pyramid the firmest of all structures?

75. What is the relation of upright position to stability? What is stated of the tower of Pisa?

76. Give the familiar illustrations in § 105. What is said of the support of the centre of gravity in animals?

77. What is said of the skill exercised in walking? What of the mode of walking in a child? What of the motions of the centre of gravity in walking?

78. What is said of the walking of a man with wooden legs? Illustrate the management of the centre of gravity in different attitudes. Describe and explain the way in which one rises from a chair.

79. State and explain the wager case. What is said of unstable equilibrium? Give the illustrations.

CHAPTER VII.

80. What is said of the phenomena treated of in Hydrostatics? What are the two characteristics of liquids? What makes a liquid have a level surface? Give the explanation. Give the comparison of the shot.

81. What is said of water as a mirror? Show that the surface of a liquid is not strictly level. If the earth had no elevations of land why would it have a perfectly globular covering of water?

82. What is a so-called perfectly level surface? What is the variation per mile from a real level? Describe the spirit-level. Give the comparison between a trough and a river.

83. What is said of the declivity of rivers? How have some rivers been made? What is stated in regard to the River Danube?

84. What is stated about the Lake of Geneva? Describe the arrangement of canal locks.

85. How are canals used for working machinery? Give various illustrations of the tendency of water to be on a level.

86. Describe the arrangement represented in Fig. 71, and give the explanation.

87. Describe a foolish man's plan for perpetual motion, and give the reason of its failure. What is said of ancient and modern aqueducts?

88. Explain the operation of springs and Artesian wells.

89. Whence comes the name Artesian? What is stated of a well in Paris? What of the situation of London? Why is the pressure of a liquid in proportion to its depth? Give the illustrations of this mentioned in § 122.

90. Explain Fig. 75.

91. What is said about the construction of dams and brewers' vats? Explain the lateral pressure of liquids. Show the difference between a liquid and a solid in this respect.

92. Show how the earth's attraction causes the lateral pressure by Figs. 77 and 78. Give the view presented in § 124.

93. What is said of the proposed ship canal between the Mediterranean and the Red Sea? Show that pressure in liquids is equal in all directions.

94. Give the illustrations in § 126. Show that the upward pressure in a liquid is as the depth, and that this is produced by gravitation.

95. State the experiment represented in Fig. 82. Give the experiment with the tube and India-rubber.

96. State the examples given of great effects produced by small quantities of a fluid. Explain these effects by Fig. 83.

97. Explain Fig. 84.

98. What is the Hydrostatic Paradox, and why is it so called? Describe and explain the Hydrostatic Bellows.

99. Describe and explain Bramah's Hydrostatic Press.

CHAPTER VIII.

100. Define specific gravity.

101. What is the most obvious way of ascertaining the specific

gravities of different liquids? Explain the sinking of heavy substances in water. Explain the rising of light substances in water. Explain what is illustrated in Fig. 87.

102. Explain Fig. 88. Explain Fig. 89.

103. Give the illustrations in § 138: lifting a stone; raising a bucket; and raising the arm in a bath. Relate the anecdote of Archimedes. What is said of boats and life-boats? What of estimating the weight of the load in a canal-boat?

104. What is said of the specific gravity of birds? Of insects? Of fishes? What of the specific gravity of the human body, and of the prevention of drowning?

105. Give the reasons why so many are drowned that might easily be saved?

106. What is stated about children in China? Why does the body of a drowned person sink? Why does it after a while rise? What is said about wading in rivers?

107. Explain the manner in which the specific gravity of a solid may be ascertained? Give the experiment of weighing water. What is stated of Archimedes and the crown?

108. Describe and explain the hydrometer. Relate the anecdote of the Chinese. What is said of the selling of milk in Switzerland?

109. What is said of the centre of gravity in floating bodies? Give the illustrations.

CHAPTER IX.

110. What does pneumatics teach? How can you show that air is material? How that it has weight? What is its weight compared with that of water?

111. What is said of the air's being attracted by the earth? Explain why some things rise and others fall in air. How thick is the earth's air-covering?

112. How is the height of the atmosphere ascertained? At what rate does the earth move round the sun? How does it carry along the air with it? State the influence which gravitation has upon the density of the air at different heights.

113. Give the comparison of air to wool. What is said of hydrogen and balloons? In what are gases and liquids alike, and what are the results of the similarity? What is the amount of pressure of the atmosphere on each square inch of surface? Give the calculations in regard to this pressure.

114. Show why the great pressure of the air does not produce destructive effects. Describe the air-pump.

115. Explain by Fig. 95 the plan and working of the air-pump.

116. State some of the experiments with the air-pump. How can you prove that air, like water, presses equally in all directions? State the comparison about the fish.

117. What is said of the Magdeburg hemispheres? Give the experiment with mercury. Explain the operation of the boy's sucker.

118. Give the statements about sucker-like arrangements in animals. State the experiment of the bladder and weight. Give the experiment with the India-rubber bag.

119. State the experiment with the egg. Explain the operation of the hydrostatic balloon.

120. Explain the operation of the Cartesian image. What is said of the presence of air in various substances?

121. What is said of the elasticity of air? Describe and explain the condenser.

122. Describe and explain the gasometer. Show how the air-gun operates. Explain the pop-gun.

123. Explain the operation of gunpowder. Explain that of steam. What is said of retardation by condensed air in gunnery?

124. Describe and explain what is represented in Fig. 113. Explain the collection of gases in the pneumatic trough.

125. Explain the experiment represented in Fig. 115. What is said of tapping a barrel? What causes the gurgling sound when a liquid is poured from a bottle? How high a column of water will the pressure of the atmosphere sustain? How do you find from this the pressure of the air on every square inch of surface? How high a column of mercury will the atmosphere sustain?

126. Explain the barometer. Relate the incident given by Dr. Arnot.

127. Why would not a water-barometer answer? What is said of the barometer as a measurer of heights? How is the boiling point influenced by the amount of the air's pressure? Give the experiment with ether.

128. State the experiment with the flask. What would happen to liquids if the atmosphere were removed from the earth? Explain the operation of the syphon by Fig. 117.

129. Explain what is represented by Fig. 118.

130. Explain the uses of the syphon. Explain the operation of the Cup of Tantalus.

131. How are intermitting springs accounted for? Explain the operation of the common pump.

132. Why does the water rise in the pump? How is sucking done? Explain the forcing pump.

133. Explain the fire-engine.

CHAPTER X.

134. What is said of the universality of motion? What of attraction as a cause of motion? What of heat? What of chemical agencies? What of life?

135. What is meant by saying that action and reaction are equal?

State the illustrations of this truth which are given. Describe Barker's mill.

136. Give the comparisons to the operation of a spring, of firing of a cannon, and the throwing of stones from the crater of a volcano. What is said of the jumping of a man from the ground?

137. What is said of the reaction in the case of a hopping bird? Illustrate the inertia of matter as shown in the communication of motion. Give the illustrations of the fact that time is required to communicate motion to bodies.

138. Give illustrations of inertia as shown in the disposition of motion to continue.

139. Describe and explain the equestrian feat represented in Fig. 127. What is said of skill in jumping from a moving carriage? Relate the case in court which is stated.

140. What is said of the course of bodies thrown into the air? What of a man falling from a mast-head?

141. What is said of the atmosphere as revolving with the earth? What rapid motions are we subjected to when we speak of ourselves as at rest? Why are we insensible to these motions?

142. Follow out in full the comparison of the steamboat. What is the difference between absolute and relative motion? What is said of absolute rest?

143. Illustrate the truth that all the motions which are apparent to the eye are slight differences in the common absolute motions. What are the obstacles to motion? How is the motion of a stone thrown upward destroyed? What causes and what opposes its descent?

144. State and explain the experiment with the lead and feather. Explain the operation of the water-hammer. Show the relation of bulk to the resistance of liquids and gases.

145. Illustrate the relation of bulk to the motion of solids produced by moving gases and liquids.

146. What is said of the opposition of gravitation to water and air in moving solids? What difference does the presence of obstacles make in the relation of force to velocity?

147. State the law of the relation of force to velocity, and illustrate by Fig. 130. What are some of the practical applications of this law? What is said of the relation of shape to velocity? What is said of the shape of fishes?

148. What is said of the shapes of boats? What of the management of the webbed feet of water-fowls? What of the wings of birds? What is said of friction as an obstacle to motion? What of it as a cause to motion? Illustrate fully in the case of the wheel.

149. What is said of the friction of liquids in tubes? What is the effect of sudden turns in pipes? What is the arrangement of arteries in the heads of grazing animals? Illustrate the difference of friction in small and large pipes by Fig. 131.

150. What is said of the effect of friction in brooks and rivers? In what part of a stream does the water move most rapidly? Explain the formation and breaking of the crest of waves rolling over a beach. What is said of the velocity of rivers as affected by friction? Explain the formation of waves.

151. What is it that really advances in the forward movement of a wave? Give the comparison mentioned. What is said of the height of waves?

152. What is momentum? Upon what two things does it depend? Illustrate this dependence. Explain Fig. 133.

153. Give the illustration of the musket-ball and cannon-ball. Give that of the plank. That of the candle. That of the air.

154. What is said of the expression, quantity of motion? Under what circumstances may a single impulse produce a great velocity? What examples have we of this? How is it with the motions that we see around us? What is said of the fall of bodies to the earth?

155. Give examples from muscular action. Give that of the arrow. Give that of gunpowder. What is said of the arrest of great velocities? Give the illustrations in regard to cannon-balls.

156. State and explain the feat of the anvil. Give examples from common efforts and labors.

157. Explain the communication of motion in the case of elastic bodies by Figs. 133 and 134. What is said of the reflection of motion?

158. What is said of the uniformity of motion? What of its uniformity in velocity? State by what means we calculate as to time.

159. What is said of the sun-dial? What of the hour-glass? What of Galileo and the pendulums? Explain the operation of the pendulum.

160. Explain Fig. 137. Explain the operation of the gridiron pendulum by Fig. 138.

161. What is said of the disposition of motion to be straight? Why is motion never straight, so far as we know? How can we make motion very nearly straight? Give the illustration of the bullet in full.

162. Give the illustration represented in Fig. 141. What is compound motion? Illustrate straight compound motion.

163. Explain Fig. 143.

164. Explain what is represented in Figs. 144, 145, and 146.

165. Explain Fig. 147. How is curved motion produced? Give the illustration of the ball and string. What are centrifugal and centripetal forces?

166. What are these two forces in the revolution of the earth around the sun? Give various illustrations of the operation of centrifugal force.

167. What is said of the formation of bends in rivers?

168. Show how eddies and whirlpools are formed. How is the

centrifugal force used in the art of pottery. How in making window-glass?

169. Describe and explain the operation of the steam-governor.

170. What is said of the agency of the centrifugal force in shaping the earth?

171. Explain the operation of the apparatus represented in Fig. 154. What are the forces which act on a projectile? What is said of balls thrown horizontally from cannon with different velocities?

172. Show by Fig. 155 why a ball dropped from the mouth of a cannon will fall to the ground in the same time that one fired from it will. By what two forces is a falling body acted upon?

173. Explain Fig. 156. What is the course of a ball dropped from a railway car or from a mast-head? Give the comparison between the cannon-ball and the moon.

174. What is said of the velocities of the heavenly bodies?

CHAPTER XI.

174. What are the Mechanical Powers? Why is the term power not strictly proper?

175. Explain the terms power, weight, and fulcrum. What is said of the use of the lever? What is the lever of the first kind? What is said of its force?

176. What is said of scales? What of steelyards?

177. Give examples of the first kind of lever. Show by Fig. 159 that there is no gain of power in this lever.

178. Give the illustration of the see-saw. What is said of Archimedes's lever?

179. State the analogy between this lever and the Hydrostatic Bellows, Bramah's Press, etc. What is the lever of the second kind? Apply the rule of equilibrium to it. Show how the common wheelbarrow is a lever of this kind.

180. Give other examples of the second kind of lever. What is the lever of the third kind? How does this differ from the other two kinds? Apply the rule of equilibrium to it.

181. Give examples of the third kind of lever. Show how it acts at a mechanical disadvantage in the different examples mentioned. State in full what is said of muscular action.

182. Explain by the figures the operation of compound levers.

183. State the comparison between the lever and the wheel and axle. What is said of the common windlass?

184. Describe and explain the capstan. What are its chief uses? What is said of the fusee of a watch?

185. Describe the arrangement of the fixed pulley. What are its uses?

186. Describe the arrangement of the movable pulley. Show how

the relation of the power to the weight is estimated in the case of compound pulleys.

187. Explain the mechanical advantage of the inclined plane. Give examples of it.

188. What is said of roads? Give the comparison of the wedge to the inclined plane. How is the power of the wedge estimated? Give examples of the wedge.

189. What is said of the screw? Show by Fig. 180 how the force of the screw is estimated. What are some of the uses of the screw?

190. Give the estimate of the power of the screw and lever as used together. How can you show that there are really but three mechanical powers? What is said of these as composing tools and machinery? What is said of friction in machinery?

191. What is the first advantage of the mechanical powers which is mentioned? Give the illustrations. What is the second advantage? Give the illustrations.

192. What is the third advantage? Give examples. How is the velocity of motion in machinery usually varied? What is the fourth advantage? Mention examples. Describe the instrument called a Lewis.

193. What is said of the title by which Aristotle distinguished man from other animals?

CHAPTER XII.

194. What is sound? What relation has sound to rapidity of vibration? Mention cases in which the vibration of sounding bodies is manifest to the sight and touch. What is said of wind instruments?

195. State the analogy of a sounding body to a pendulum. Describe the process by which the sensation of sound is produced. Where does the vibration caused by the sounding body stop in the ear? What is transmitted from thence to the brain?

196. Give examples of the transmission of sound through various substances? State the experiment by which it is shown that sound is not transmitted through a vacuum. What is said of sound at great heights?

197. How far has the sound of a volcano been heard? If the same sound were made in space at that distance from the earth why could not the inhabitants hear it? What is the cause of the noise of bodies passing through the air? Why do the heavenly bodies, moving so rapidly, produce no sound? Cite examples showing the different velocities of sound in different media.

198. What is said of the uniformity of the velocity of sound? Show how we can measure distances by sound as compared with light in velocity. Upon what does the loudness of sound depend? Illustrate this point.

199. What is said of the diffusion of sound? What of its reflection? What of echoes?

200. What is said of multiplied and mingled reflections of sound? Explain the operation of whispering galleries by Fig. 187.

201. Explain the operation of the speaking-trumpet. Give other examples of the concentration of sonorous vibrations.

202. What is the difference between a musical sound and a noise? What is said of the exact regularity of musical vibrations? How are different notes produced in stringed instruments? Upon what does the note depend in wind-instruments?

203. Explain the operation of the organ-pipe represented in Fig. 190. What is said of the notes of bells and of musical glasses? Explain the mechanism of the human voice.

204. What is harmony? Upon what does it depend? Between what two notes of the scale is there the greatest harmony? What note next to the octave harmonizes best with the fundamental note? And what note next? Show why the second note, in contrast with the octave, is so discordant with the fundamental note.

205. State the proportions between the numbers of the vibrations in the different notes. If you know the number of vibrations of the fundamental note in a second, how may you determine the number of vibrations in the other notes? What is said of the number of notes in the diatonic scale? What of the proportionate lengths of strings for different notes? What is said of tuning instruments?

206. What is meant by saying that a note is too sharp or too flat? State in full what is said about the mysteries of sound and hearing.

CHAPTER XII.

207. State the experiment of the three vessels, and the inference from it.

208 What other facts sustain this inference? How did Sir Humphrey Davy prove that there is heat in ice? What are the two theories of heat? What is the chief source of heat for the earth? What is said of the heat of the sun itself?

209. What is said of the universal influence of the heat of the sun in the earth? What of the heat supplied from within the earth itself? What of electricity as a source of heat?

210. What is said of chemical action as a source of heat? Give examples of the production of heat by mechanical action. What is said of the relations of heat and light?

211. Show the expansive influence of heat by describing the experiment represented in Fig. 192. Give familiar examples of this expansion.

212. How can you loosen a stopper stuck fast in a bottle? Give the anecdote about the *Persia*. Give the statement about the building in Paris.

213. What is said of the expansion of liquids by heat? How may the influence of this expansion upon specific gravity be shown?

214. What is said of thermometers? What of the invention of the thermometer?

215. State the plan of Fahrenheit's thermometer. Give the plans of other thermometers.

216. Why is Fahrenheit's thermometer, on the whole, the best? What is said of the expansion of gases by heat? State experiments in illustration.

217. What is said of balloons? What of the influence of heat on the atmosphere? Give examples of this influence.

218. Why, in heating apartments, do we have the heat created or introduced at as low a place as possible? Explain the *draught* of a chimney. Why does a stove-pipe generally draw better than a chimney?

219. State the experiment with the candle and the door. What is the explanation of the occurrence of wind? Explain the land-breeze.

220. Explain the sea-breeze. How are winds affected by the rotation of the earth?

221. Show by Fig. 201 why the prevailing winds at the equator are northeast and southeast.

222. Mention the melting points of various substances. What is said about the natural state of water and other substances? What are the two modes of changing a liquid into vapor?

223. What is said of the rapidity of evaporation? What of the solution of water in air? What influence has heat upon the capability of air to dissolve water? What phenomena illustrate this? How is it supposed that water rises in air? What fact is in opposition to this supposition?

224. What becomes of the water that rises in the air? What is said of the formation of fog and of clouds? Mention the different shapes of clouds and their names.

226. What is said of the influences that give shape to clouds?

228. State how rain is produced, and explain Fig. 208. How are snow and hail formed? What is said of vaporization?

229. What influence has pressure upon the formation of vapor? Give the experiment with ether in illustration. Describe the experiment represented in Fig. 209. What is said of Papin's digester?

230. What is said of steam? In what consists the power of the steam-engine? How is the expansive force of the steam in the boiler estimated? Describe the working of the engine by Fig. 210.

231. What is the difference between high and low pressure engines? What is said of the communication of heat? How many modes of communication are there, and what are they? What is the mode called convection?

232. Give examples of convection. What is the *conduction* of heat?

233. State the experiment represented in Fig. 211. State the experiment represented in Fig. 212. What is said of non-conductors of heat? Give the examples cited.

234. Explain Davy's safety-lamp.

235. Give what is stated in the note about Stephenson and Davy. What is said of the influence of density on the conduction of heat? Give the illustration about melting snow.

236. State the experiments which show that liquids are poor conductors of heat. What is said of air as a non-conductor of heat? What is said of double windows?

237. What is said of arrangements of the walls of buildings? What of an arrangement for preventing the spreading of fires in blocks?

238. How are animals in very cold regions protected from the cold? What is it in their coverings that affords the protection? What is said of the coverings of quadrupeds that are natives of warm climates? What of the elephants whose remains are found in Siberia?

239. What changes take place in the coverings of animals carried from a cold to a warm climate, and the reverse? Why has man no covering against the cold? Explain the object of clothing. What is said of articles of clothing? What of loose clothing? What of coatings of straw put on trees? What of bricks compared with stones?

240. What is said of cocoons? What of buds of plants in winter? What of snow as a protection of plants?

241. State the arrangement of snow observed in the arctic regions. State in full what is said of the influence of the conduction of heat upon sensation.

242. What is meant by the radiation of heat? Give examples of it. What is said of the connection of heat and light in the rays of the sun? What is said of heat from a common fire?

243. What is said of the relation between absorption and radiation? What of the reflection of heat? State the experiment with the mirrors and the thermometer and flask.

244. Explain the experiment with the ice. Give the experiment with phosporus. Give the experiment represented in Fig. 218.

245. Explain the formation of dew. State the analogy of the tumbler. What is said of the circumstances that influence the deposition of dew and frost?

246. What is said of different substances in regard to the deposition of dew? What about Gideon's fleece? What is the dew-point? How can you ascertain it?

247. What is said of the freezing of mercury? Explain the difference between sensible and latent heat. What is said of capacity for heat? State the experiment represented in Fig. 219.

248. What is the relation of heat to density? Give the illustrations.

249. What is the reason that the air is so cold on great heights? What is the relation of heat to the forms of substances? What is said of the melting of ice? What of the vaporization of water? State the general conclusion in regard to latent and sensible heat.

250. State in full what is said of latent heat in reference to clouds. Explain the operation of freezing mixtures.

251. State the examples of the production of cold by evaporation.

252. State and explain the experiment represented in Fig. 221.

253. Give the facts stated in regard to the degree of heat which man can endure. Give the reasons why the heat did not produce a greater effect in these cases.

254. What effect does heat produce upon the bulk of substances? What is said of water as an exception? Describe the process of freezing as illustrated by the diagram.

256. What would be the process if the exception did not exist? State what would be the results.

257. What would be the consequence if the freezing point were above 32°? What if it were below? What is said of the force of expansion in ice? What are some of the benefits which come from this expansion?

CHAPTER XIV.

258. What is Newton's theory of light? What is the undulatory theory? State the analogies to sound and heat. When is a body luminous? What are the sources of light?

259. How may you see that light moves in straight lines? State various familiar recognitions of this fact. Illustrate the fact that the intensity of light is inversely as the square of the distance.

260. What is said of the velocity of light in regard to ordinary distances? How long is light coming from the sun to the earth? What is said of the light coming to us from certain stars?

261. Give the observation of Roemer represented in Fig. 226.

262. What is said of the reflection of light? What of its reflection in relation to seeing? What of the images formed in mirrors?

263. Show by Fig. 228 why the image in a mirror seems to be at the same distance behind it that the object is before it. Explain by Fig. 229 the operation of the kaleidoscope.

264. Explain the operation of a concave mirror by Fig. 230. Explain that of a convex mirror by Fig. 231.

265. What is meant by the refraction of light? Illustrate its refraction in passing from a denser into a rarer medium. Then from a rarer into a denser.

266. How is the refraction in regard to a perpendicular in the two cases? Explain dawn and twilight. Explain what is represented in Fig. 234.

267. What are mirages? Describe the mirage which occurred at

Ramsgate. Describe that seen by Captain Scoresby. Relate the incident which occurred at New Haven.

268. What is said of mirages in deserts?

269. Describe the mirage of the French coast. Explain what is meant by the visual angle as illustrated by Fig. 236.

270. Explain Fig. 237. What are lenses? What are the different kinds?

271. What is the difference of effect in convex and concave lenses? Explain the effect of a convex lens on the visual angle. What is said of microscopes and telescopes?

272. Describe and explain the magic lantern. Describe and explain the camera obscura.

273. Describe the arrangement of a camera for sketching. How is the eye like a camera?

274. Describe the arrangement of the parts of the eye as mapped in Fig. 244.

275. Show now particularly how the eye is like a camera. What is said of the influence of the cornea on the light? Show what is required for distinct vision, as illustrated in Fig. 245. Show why it is that objects brought very near the eye are not seen distinctly.

276. What is said of the microscope? Explain the difficulty in the near-sighted. In the far-sighted.

277. How can you show that the images of objects in the retina are inverted? Give in full what is said of explanations of the fact that we see objects erect notwithstanding this inversion. Explain single vision.

278. By what simple experiment can you show the explanation of single vision to be correct? What is said of squinting? Explain the stereoscope.

279. What is said of distinct impressions on the retina? Explain the thaumatrope.

280. State in full what is said of the compound nature of light. Give the proportions of the colors in it. What is said about there being only three colors?

281. What is said of the recomposition of decomposed light? Give the illustration of the powder—the circular board—the top.

282. What is said of the colors of substances? What of the variations of these colors in different lights? What of variations with varying positions? What of the colors of clouds?

283. Explain the formation of the first rainbow by Fig. 253. Explain the formation of the second bow by Fig. 254.

284. What is said of the circumstances under which rainbows are seen?

285. Explain in full the formation of the two bows as illustrated by Fig. 255. What is said of the bow as seen by different persons, and at different moments by the same person? What of rainbow hues in dew-drops and ice-crystals?

286. Give the dissection of light as represented in Fig. 256. What is said of Daguerreotyping?

CHAPTER XV.

287. What is the origin of the term electricity? What is said of attraction and repulsion in electricity?

288. What is the supposed explanation of electrical repulsion? Explain the difference between resinous and vitreous electricity. What is said of the two supposed electrical fluids? Detail the illustrations of attraction which are stated.

289. State the theory of Franklin. Explain the use of the terms positive and negative. Illustrate the fact that the kind of electricity excited depends on what a substance is rubbed with.

290. What is said of the incorrectness of the terms vitreous and resinous? What is said of conductors and non-conductors? Why are non-conductors called insulators?

291. What marked difference is there between heat and electricity? State the experiment represented in Fig. 258. What is said of electrics and non-electrics?

292. What is said of equilibrium in electricity, and of its disturbance? Give in full what is said of the universality of electricity.

293. State what is said of induction, as illustrated by the experiment represented in Fig. 259.

294. State the experiment represented in Fig. 260. Describe the arrangement and operation of the electrical machine represented in Fig. 261.

295. Describe the cylinder machine. State the experiment with the pith balls. State that with the head of hair.

296. State the experiment with the tissue-paper. State that with the dancing figures. State that with the bells.

297. Describe the experiment with the tin-foil. Describe the insulating stool and the operation of it.

298. What is said of the escape of electricity from points? Describe the apparatus represented in Fig. 269, and the operation of it. What is said of the discharge of electricity from a point in a dark room? Describe the Leyden jar.

299. Explain the operation of the Leyden jar. What would be the effect of connecting the inside foil with the outer by a strip of foil? Give in full the experiment represented in Fig. 272, and the explanation.

300. What is said of the discharge of the jar? How can a large number of persons take a shock from it together?

301. Explain the effect of moisture upon the charged jar. State the experiment represented in Fig. 274.

302. What is the electrical battery? What is said of the light produced by electricity?

303. To what is the report of electricity owing? What is said of mechanical injuries caused by electricity? What of the heat caused by it? What effects may be produced by this heat?

304. What was the discovery of Franklin, and how did he make it?

305. Relate the accident which occurred at St. Petersburg. What is said of lightning-rods?

306. What was Sulzer's experiment? What were Galvani's observations?

307. What is said of the pile of Volta? What of his cup battery and of other batteries?

308. What difference is there between frictional and voltaic electricity?

CHAPTER XVI.

308. What are loadstones? Where do they abound? What is said of discoveries in magnetism? Whence come the terms magnetism and magnet?

309. What is said of the attraction of magnetism? What law is there in regard to it? What is said of the poles of a magnet? What of magnetism by induction?

310. What is said of attraction and repulsion in magnets? Explain the formation of the curves of iron filings in the experiment represented in Fig. 282.

311. How may artificial magnets be made? What is said of the horseshoe magnet and its armature?

312. What is said of the magnetic needle and the mariner's compass?

313. What is the declination of the needle? When was it first observed? What is said of observations after this? What is said of the dip of the needle?

314. What is said of the earth as a magnet? What of it as a magnetizer?

315. What is said of fixing magnetism? What of impairing it? In what other substances besides iron does magnetism exist? In what is magnetism like electricity? In what is it unlike it?

316. What relation has magnetism to electricity? What were the original observations of Oersted in regard to it?

317. Describe the manner of making the most powerful electro-magnets. Describe the experiment represented in Fig. 287.

318. Show the application of electro-magnetism in the electric telegraph.

319. What is the contrivance called the signal key? How is the alphabet of Morse's Telegraph constructed?

320. What is said of the communication through the earth in telegraphing?

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